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Richard K. Blauvelt, Roy W. Zocher
and Stanley E. Bronisz

October 15, 1981

Monsanto

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Miamisburg, Ohio 45342

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MONSANTO RESEARCH CORPORATION
a subsidiary of Monsanto Company

for the
U. S. DEPARTMENT OF ENERGY
Contract No. DE-AC04-76-DP00053

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Contents

Introduction

The SARP includes discussions of structural integrity, thermal resistance, radiation shielding and radiological safety, nuclear criticality safety, and quality control.

The GPHS module shipping container is designed to transport three encapsulated General Purpose Heat Sources (GPHS) outside the plant boundaries. It meets the requirements of the Department of Transportation and the Department of Energy. A complete physical and technical description of the package is presented. The GPHS module shipping container consists of three stainless steel cans that sit inside a finned cask that is completely enclosed within a cage-type carrier.

The finned cask is a stainless steel vessel which was first designed for the SNAP-19 program and, with limited modifications, is used for the GPHS module. External fins are provided to dissipate the heat from the radioactive decay of the plutonium. The stainless steel can (SSC) was designed solely to hold the GPHS module inside the finned cask. The SSC is a completely welded cylinder. It passed the normal and hypothetical accident conditions, but is not designed to dissipate heat. The carrier consists of a metal mesh cage welded to a steel base, which can be easily handled using a fork lift or hand pallet truck.

The contents of the shipping container consist of three GPHS module heat sources producing a total of 750 W of heat from the decay of plutonium-238 in the form of a solid oxide. The GPHS module shipping container demonstrated the ability to dissipate up to 820 W of thermal decay energy. Each GPHS module heat source contains approximately 454 g of encapsulated plutonium-238 isotope or a total of 1360 g of plutonium-238 for the entire shipping container. The overall dimensions of the module are 2.14 x 3.71 x 3.81 in. Each module contains four PuO_2 pellets. Each fuel pellet is contained in a vented iridium capsule. Two of the iridium capsules are enclosed in a single impact shell, which in turn is enclosed in two layers of pyrolytic graphite. Two of these pyrolytic graphite-enclosed impact assemblies are held in a reentry member. Details of the GPHS-Module design are provided in the Contents of Packaging section of this report. Because of the DOE requirements for double containment, it is intended that the contents of the GPHS module shipping container be limited to the General Purpose Heat Source.

Established quality control practices were used from the inception of the GPHS module shipping container to the final inspection and packaging operations.

Extensive tests and evaluations were performed to show that the container will function effectively with respect to all required standards and when subjected to normal transportation conditions and the sequence of four hypothetical accident conditions (free drop, puncture, thermal, and water immersion). In addition, a steady state temperature profile and radiation profile were measured using two heat sources that very closely resemble the GPHS. This gave an excellent representation of the GPHS temperature and radiation profile. A nuclear criticality safety analysis determined that all safety requirements are met.

Conclusions

When packaged within the specified limits, the GPHS module shipping container is in compliance with the requirements of the DOE [1] and the DOT. When the package is fabricated in accordance with specified standards, it will maintain its integrity during normal transport conditions and will not release radioactive materials during hypothetical accident conditions.

This section of the SARP summarizes the conclusions determined in the subsequent sections of the report. The parameters that are essential to the safe use of the shipping container are established in these sections.

The shipping container is used for offsite shipment of three GPHS modules. Each module consists of four PuO_2 pellets. Each fuel pellet is contained in a vented iridium capsule. Two of the iridium capsules are enclosed in a single impact shell, which, in turn, is enclosed in two layers of pyrolytic graphite. Each module satisfies the requirement for primary containment during normal and accident conditions. The SSC around each module satisfies the need for double containment so that no PuO_2 is released during normal or accident conditions. Evaluation of the heat source materials proved that they will not cause the packaging to be breached under accident test conditions.

Because of the necessity for double containment, the contents of the GPHS module shipping container are limited to the GPHS modules.

The internal pressure capability was established by hydrostatically testing an SSC. No bulging of the container occurred until after 200 psig. ASME code requires that a pressure vessel be tested at 150% of its design pressure, so under this criterion, the SSC could withstand an internal pressure of 133 psig. To achieve this pressure by increasing temperature requires an increase to 4000°F.

Related testing and engineering evaluations adequately demonstrated that the requirements of the normal conditions of transport tests (heat, cold, pressure, vibration, water spray, free drop, corner drop, penetration, and compression) are satisfied although no tests were specifically performed for this purpose. Heat from direct sunlight at 130°F (54°C) or cold of -40°F (-40°C) will not increase or decrease the temperature of the packaging beyond design capabilities. The 7.3 psi (0.5 atm) reduced external pressure requirement is well within the design capability. Road vibration, 4-ft free drop, or 1-ft corner drop will not significantly reduce the effectiveness of the package. No water spray test was made; however, the package was immersed in water for 24 hr with no adverse effect. Calculations showed that the finned cask is capable of withstanding 770 times the energy available from the penetration test without yielding and 300,000 times the energy load specified in the compression test without exceeding the maximum allowable stress.

Extensive testing and evaluation of the shipping package and an unprotected SSC to the four hypothetical accident tests verified that no PuO_2 will be released, and the finned cask and cage will not harm the SSC.

Two 30-ft drop tests were performed using both a full-scale GPHS module shipping container, packaged with three SSCs containing lead shot to simulate the heat source weight, and a "bare" SSC with lead shot. The complete shipping package was first dropped on a corner of its top and then on a corner of its bottom. There was no damage to the finned cask. The shipping cage was extensively damaged but was securely attached to the finned cask. Other than two small indentations at the points of impact, the separate SSC was undamaged.

Both the SSC and shipping package were "burned" for a total of 50-min. There was, however, a 30-min portion of the burn where the temperature of the two controlling thermocouples averaged 1475°F. The SSCs inside the finned cask encountered a maximum temperature of 900°F, and the SSC that was unprotected had a maximum temperature of 1525°F. Most fins on the finned cask were melted at least a quarter of the way through.

Both the SSC and the GPHS shipping package were immersed under water for 24 hr. Upon completion of the water immersion test, the four SSCs (the three inside the finned cask and the one by itself) were helium leak tested. No leaks were detected.

Calculations for the puncture drop indicated that, to be punctured, the finned cask required 56 times the available energy, and the SSC required twice the available energy.

External temperature measurements were made on two Rite heat sources (420 W and 820 W) that were being stored in two unmodified SNAP-19 containers to determine the steady state temperature profile of the GPHS module. A maximum temperature of 146°F was measured at the finned cask top, and the body of the finned cask and outside fin edge had temperatures of 135°F and 126°F, respectively. Under the cage a temperature of 127°F was recorded, and the outside edge under the cage read 113°F. An SSC with a heating tape, thermocouple, and pressure gauge installed produced an internal temperature of 608°F at 300 W with a corresponding pressure of 18 psig.

Extensive evaluations showed that the container will function effectively with respect to all required standards. In Part II of MC0529, general DOE standards are specified for materials, closures, lifting devices, and tiedown devices in addition to structural standards pertaining to load resistance and external pressure. Positive closures prevent inadvertent opening, and seals are secured to the closures during shipment. The lifting lugs for the finned cask cover, the carrier baseplate which is used for lifting the entire container, and the tiedown rings are shown to satisfy all requirements. The package capability exceeds the load resistance requirement by a factor of 10,000 and exceeds the external pressure requirement by a factor of 140.

The criticality safety analysis, based on the density analog technique, established that the amount of plutonium-238 that can be packaged per container in a 2500 container array is 2.4 kg. For the authorized maximum contents of 1.5 kg, a total of 4400 packages would comprise a subcritical array.

The radiation shielding evaluation using the Rite heat sources (420 W and 820 W) inside unmodified SNAP-19 containers showed that the total dose rate at any accessible point on the surface of the shipping container will be less than 200 mrem/hr as required; however, the Transport Index as measured 3 ft from the side of the shipping container will slightly exceed 10 mrem/hr. Thus, "sole-use of ve... e" shipments are made in order to satisfy regulations.

Established quality control practices were implemented during all phases of fabrication of the heat source and the shipping container. All welds on the SSCs were at least dye penetrated. Visual, dimensional, and functional inspections were performed.

1 Package description

1.1 General

This description of the packaging is intended to provide sufficient information regarding the design intent and sufficient design detail to accurately identify the General Purpose Heat Source Module Shipping Container and to provide the basis for evaluation of the packaging. The gross shipping weight is approximately 1,100 lb, and the overall size is a 38 in. cube. Three containers were fabricated or modified in accordance with the following Mound drawings and specifications:

MRC Drawing FSD-18877	Modification of SNAP-19 Shipping Case for GPHS Module.
MRC Drawing AYD-790452 Sheet 1 and 2	Shipping Cylinder for GPHS Module.
MRC Drawing 1-14841	Welding and Inspection of 304L S.S. Containers.

The GPHS module shipping container consists of a shipping cage that completely encloses a finned cask. Both the finned cask and shipping cage were originally made for other programs and modified for GPHS use. A stainless steel can (SSC) was designed to hold the actual GPHS module. Three SSCs are stacked on top of each other and shipped in one finned cask. No shipping container materials are specifically used as neutron absorbers or moderators. No shielding is normally required to meet requirements for shipments in a sole-use vehicle.

1.2 Design intent

The GPHS module shipping container is designed specifically for transportation and storage of three GPHS modules. Primary containment is given by the GPHS module (see Section 2) itself, and the SSC provides secondary containment. The shipping cage and finned cask were designed so that they will not contribute to the possibility of a radioactive release, i.e., by preventing excessive damage to the primary or secondary containment vessels during normal or accident conditions.

Guidelines used for the design include criteria regarding frequency of use, storage, and handling requirements. Each SSC is to be used for only one shipment, but the shipping cage and finned cask are expected to have repeated use with different SSCs.

Handling features are based primarily on utilization of a forklift. For short moves, where a forklift is not practical, the shipping container may be moved using a hand pallet truck. The shipping package was not designed to be lifted with chains or cables from an overhead hoist. The shipping container is designed so that packaging and unpacking operations may be performed quickly to avoid unnecessary radiation exposure and with readily available tools.

It is not intended that the shipping container alone will provide sufficient shielding to meet transportation requirements; however, the combination of the shipping container and the sole-use transport vehicle are sufficient to comply with DOE/DOT requirements [1] for radiation dose levels during transportation. Shielding requirements during onsite storage are dependent on available facilities and must be evaluated as a separate requirement.

The GPHS module shipping container is designed with external fins to dissipate 750 W of heat during normal transportation in order to maintain an external surface temperature of less than 180°F (82°C) in accordance with DOE/DOT requirements for sole-use shipments.

1.3 Shipping cage

The shipping cage, which consists of a steel frame and steel mesh, is illustrated in Figure 1. The cage protects the finned cask from damage and provides personnel protection from heat and radiation. The base is constructed to serve as a two-way steel pallet. Tie-down rings on the frame (not shown) are used to secure the shipping container within the transport vehicle. The cage is of welded construction weighing approximately 300 lb. The overall height is slightly less than 38 in., including the cage lid. The overall base is 38 x 38 in.

The shipping cage is fabricated entirely of steel. It is less than 38 in. high to provide easy access to the finned cask. The base of the shipping cage is shown in Figure 2. It consists of a 38 x 38 x 1/2 in. thick steel plate with an octagon plate 1/4 in. thick in the middle. The octagon plate has eight 1/2 in. holes placed on a 10-1/2 in. diameter. These tapped holes are provided in the base plate for securing the finned cask in place using 1/2 in. - 13 x 2-1/2 in. bolts Grade 3, with proof strength of 85,000 psi. Sections of 6 x 6 x 1/2 in. thick angles are welded to the underneath side of the base plate to provide forklift or hand pallet truck access from two sides for lifting the entire shipping package. The framework is fabricated of 2 x 2 x 3/8 in. thick angle iron and 1-1/2 x 3/8 in. thick strips that act as bracing. Heavy gauge steel screen is welded to the framework so that the finned cask is completely enclosed during shipment, and it is well ventilated to permit heat to escape. The top perimeter is made of 3/8 in. thick steel plate with 1 x 3/4 x 1/4 in. thick angles as bracing. The top is bolted to the frame with 16 bolts.

The "H" that appears on either side of the octagonal plate remains from the Viking program, and they do not satisfy any specific need.

1.4 Finned cask

The cask is a 304 stainless steel vessel with 80 aluminum fins. The overall height is slightly less than 19 in., and the overall diameter from fin tip to fin tip is 25-1/4 in. The weight is approximately 840 lb. (Refer to Figure 16.)

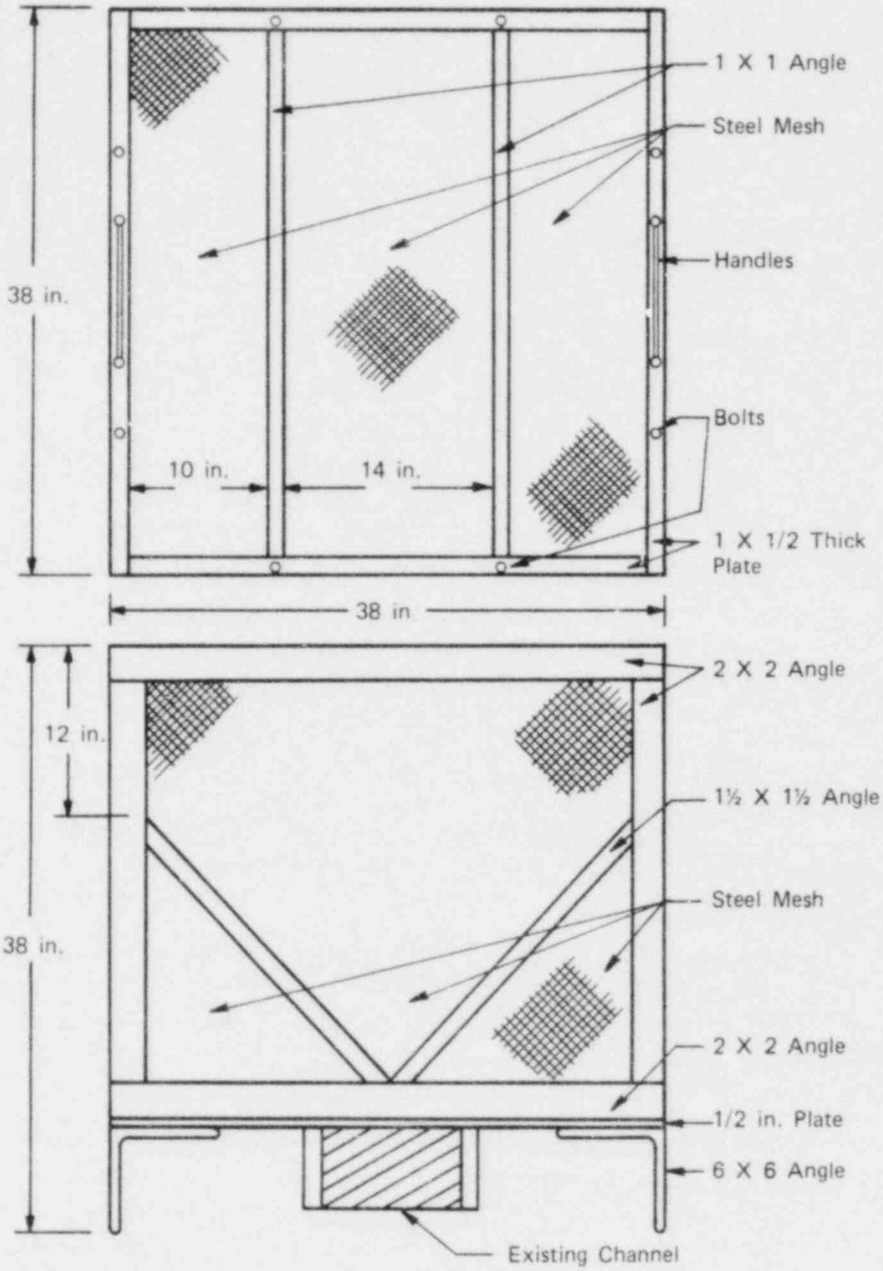


FIGURE 1 - Shipping cage.

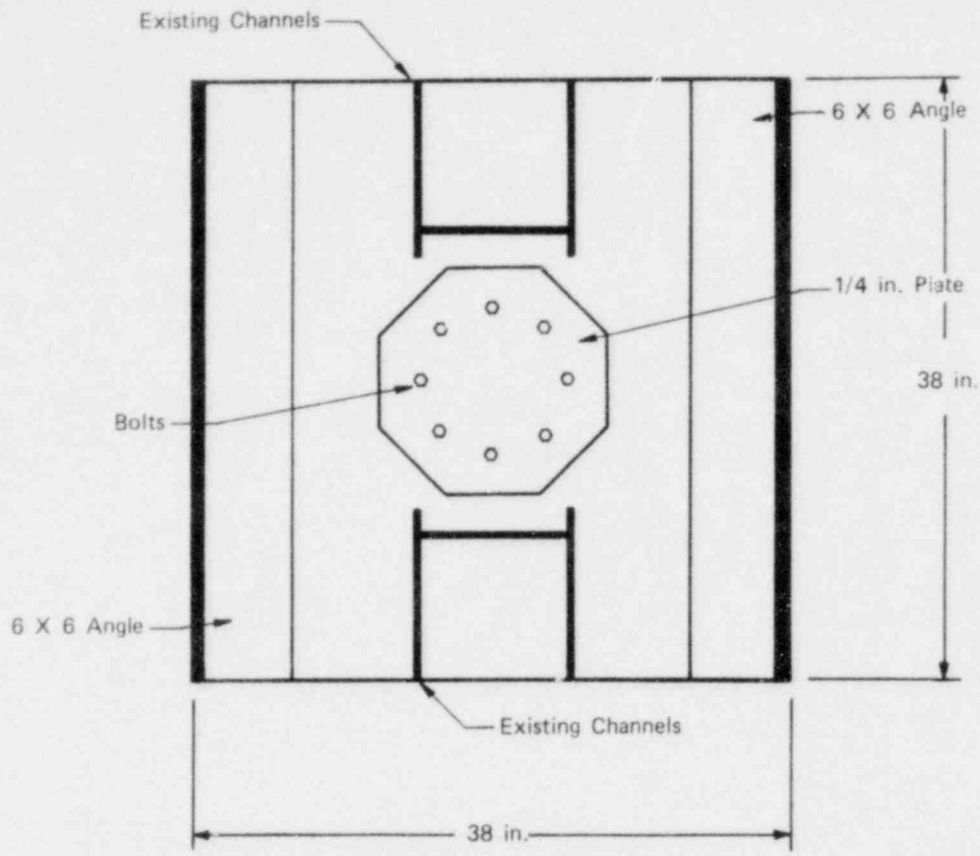


FIGURE 2 - Base of shipping cage.

The body of the finned cask is a welded 304 S.S. cylinder with a cover at the top which is sealed with a 1/4 in. cross-sectional diameter Viton O-ring. The main body is 16-3/4 in. high, 14-1/2 in. in diameter, with 4 in. thick walls and a 2 in. cover. The cover is secured with eight 1/2 x 3-1/2 in. long fine thread bolts. At four locations on the circumference of the cover are 1/2 in. - 10 x 5-1/4 in. long shoulder eye bolts which may be used to raise the cover and place the finned cask in the shipping cage but not raise the fully loaded shipping package. The bottom of the cask is 1-1/2 in. thick.

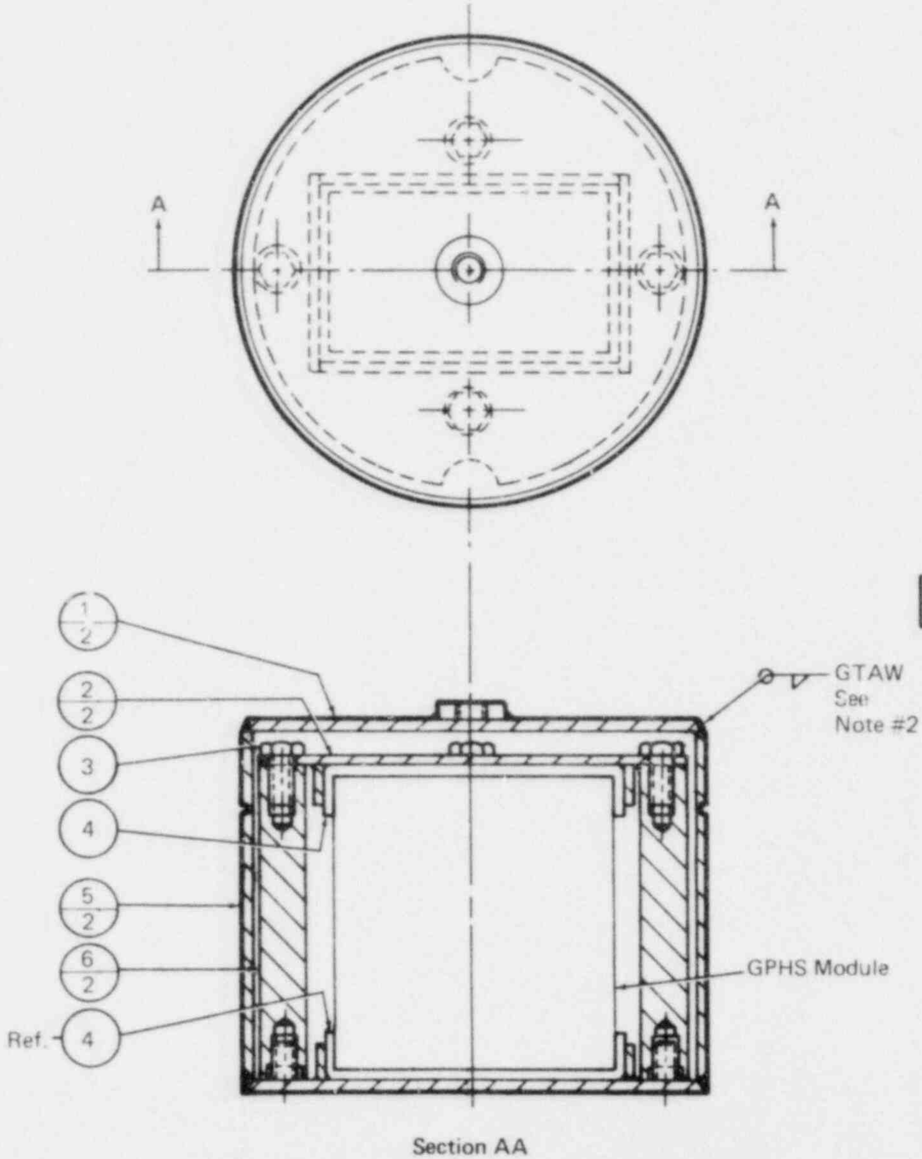
The interior of the SNAP-19 container was machined to produce a cavity 6-1/2 in. in diameter by 15-1/4 in. tall.

The aluminum fins are 13 in. high x 5-1/2 in. wide x 1/8 in. thick.

Eight holes are tapped in the base to hold the finned cask to the shipping cage using 1/2 in. - 13 x 2-1/2 in. bolts Grade 3, with proof strength of 85,000 psi.

1.5 Stainless steel can (SSC)

The GPHS module will be housed inside the stainless steel can (SSC). The SSC is a completely welded cylinder (see Figure 3) with walls of 6 in. diameter x 0.120 wall x 4-1/2 in. height 304 S.S. tubing, base plate of 6 in. diameter x 0.125 in. thick 304 S.S. sheet, and cover plate of 5-7/8 in. diamter x 0.125 in. thick 304 S.S. sheet. The interior of the SSC is designed



Notes:

1. For welding & inspection specifications see MRC Dwg. No. 1-14841 with exceptions as follows:

   Section 2:
   Para. 2.7 - The vendor is to have a certified welder perform the work & is to verify so in writing.

   Sections 4.
   5.
   6. - Will be performed by MRC. If the items do not pass dye penetrant test–radiographic examination or helium leak test the items will be rejected by MRC.

   Section 7. - Vendor shall fill out appropriate sections of "300 Series Stainless Steel Containers Fabrication & Inspection Certification."

2. GTAW cover (Det. 1) to cylinder (Det.5) after loading GPHS module in cylinder (Det. 5).

Class	Det.	Dwg. or Sht. No.	Description	Req'd.	Matl.	Stock Size
	1	2	Cover	1		Weldment
	1A	2	Cover plate	1	304S.S.	5-7/8ϕ x 1/8
	1B	2	Boss	1	304S.S.	7/8ϕ x 1/4
	2	2	Hold down plate	1		Weldment
	2A	2	Plate	1	304S.S.	5ϕ x 1/8
	2B	2	Support	2	304S.S.	1/8 x 1/2 x 3-11/16
	2C	2	Support	2	304S.S.	1/8 x 1/2 x 2-9/16
	3	1	Hex head bolt	4	S.S.	5/16-18 x 5/8
	4	1	Cushion	As Req'd.	Carbon Felt	1/4 thk. x as req'd.
	5	2	Cylinder	1		Weldment
	5A	2	Bottom plate	1	304S.S.	6ϕ x 1/8
	5B	2	Weld stud	4	S.S.	5/16-18 x 1/2
	5C	2	Cylinder	1	304S.S.	6ϕ x .120 wall x 4-1/2
	5D	2	Support	2	304S.S.	1/8 x 1/2 x 3-11/16
	5E	2	Support	2	304S.S.	1/8 x 1/2 x 2-9/16
	6	2	Post	4	Graphite POCO	5/8ϕ x 4-1/8

FIGURE 3 - Stainless steel can.

to hold the GPHS module in a fixed position during shipping with a 5 in. diameter x 0.125 in. thick 304 S.S. cover plate, and four 4 - 4 x 5/8 in. diameter Poco Graphite rods, weld studs, and bolts. There are also locators top and bottom to position the GPHS module precisely. A boss, 7/8 in. diamter x 1/4 in. thick and threaded, is welded to the top of the SSC to assist in loading and unloading. A 0.06 in. groove is provided to assist in opening with a 6 in. pipe cutter.

This SSC was designed to be helium leak tight during both normal and hypothetical accident conditions.

2 Contents of package

2.1 The general-purpose heat source (GPHS) final design

The GPHS final design is illustrated in Figure 4. It is a 250-W (nominal) module containing four PuO_2 pellets (83.5% ^{238}Pu and 63 W at time of pressing). The overall dimensions are 54.42 mm by 94.22 mm by 96.72 mm. Each fuel pellet is contained in a vented iridium capsule, and two of the iridium capsules are enclosed in a single impact shell, which is enclosed in two layers of pyrolytic graphite. Two of these pyrolytic graphite-enclosed impact assemblies are held in a reentry member. A heat source of the required size is assembled by stacking the GPHS modules. Interlock members are used to locate the modules and to resist lateral loads on the module stack. Each component is discussed briefly in this section.

2.1.1 FUEL

The GPHS fuel body is a right circular cylinder with radiused corners and an aspect ratio of one, as shown in Figure 5. Its density is 9.53 to 9.86 g/cm^3 (84 to 86% of the theoretical density of PuO_2). The density was chosen on the basis of impact tests, which indicated that impactability is a direct function of density, and fabricability trials, which showed that this density was the highest at which sound pellets of this size could be made by hot pressing. The pellets are made from a "GROG process" in which two types of powder, high and low fired, are mixed and pressed. This process yields a stable product with a homogeneous microstructure. The cylinder end radius was chosen for three reasons: 1) to reduce thermal shock problems, 2) to approximately equalize the impact stresses at various orientations, and 3) to correspond to the internal radius that can be fabricated in iridium alloy sheet of the size and thickness used for the GPHS capsule.

2.1.2 CLAD

The GPHS clad is shown in Figure 6. It is made of an Ir-0.3 wt % W (DOP-26) alloy formulated by Oak Ridge National Laboratory. The iridium alloy was chosen because the GPHS operating temperature in a Si-Ge thermelectric converter is too high for the platinum-alloy candidates for the clad. One of the two halves of the capsule contains an iridium-frit vent designed and made by Mound Facility.

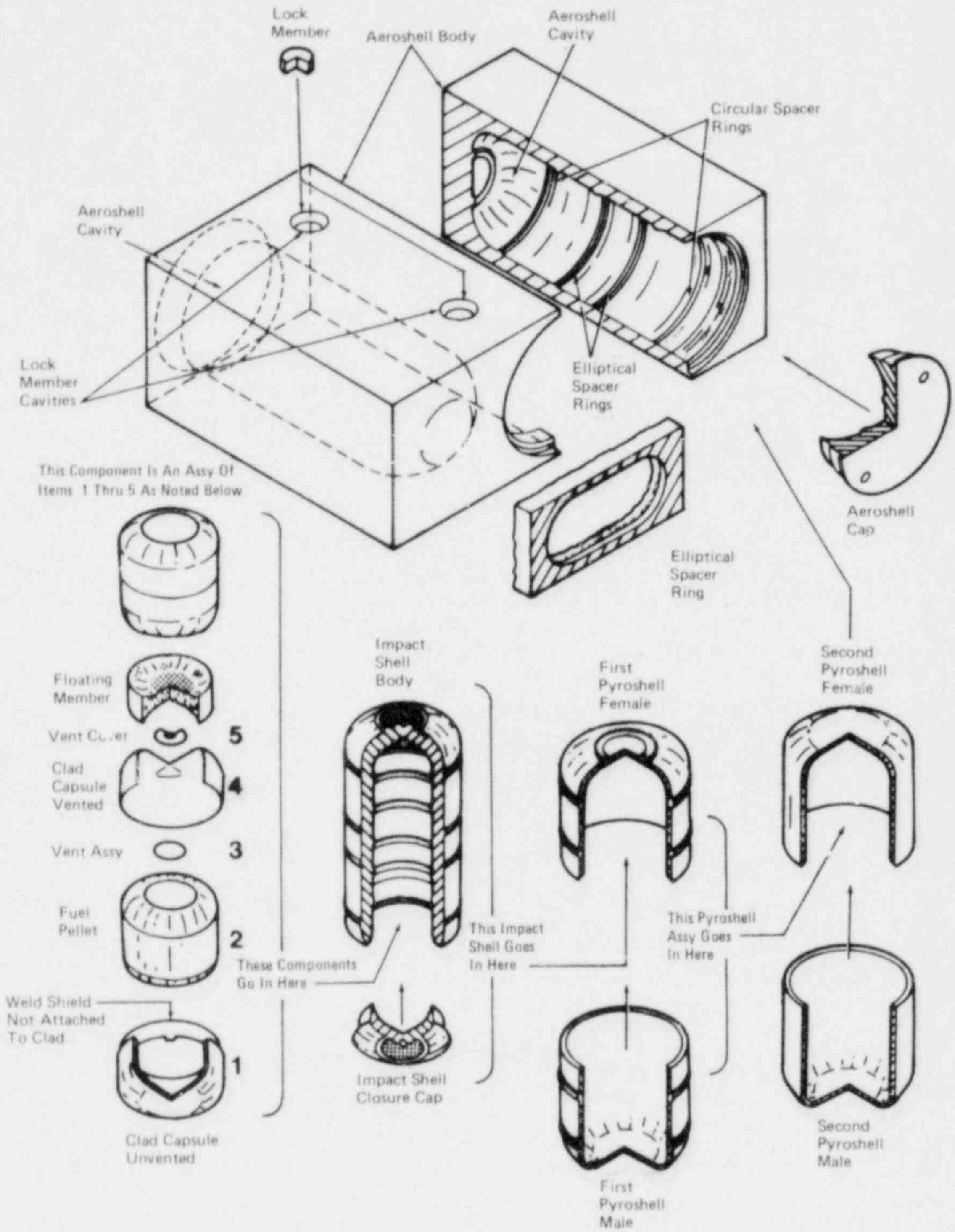


FIGURE 4 - Component assembly.

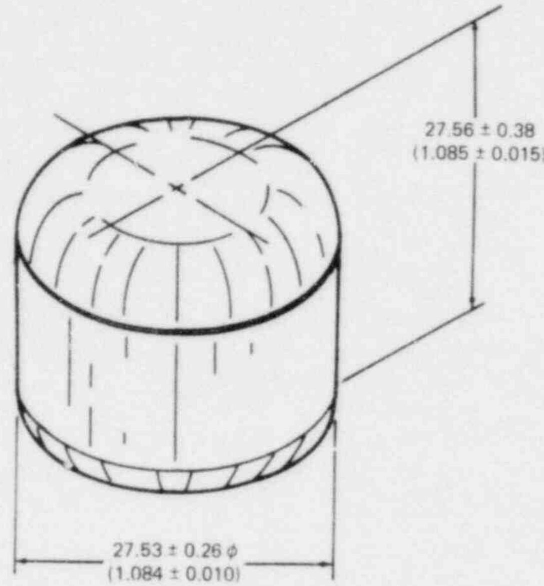


FIGURE 5 - Fuel pellet parameters.

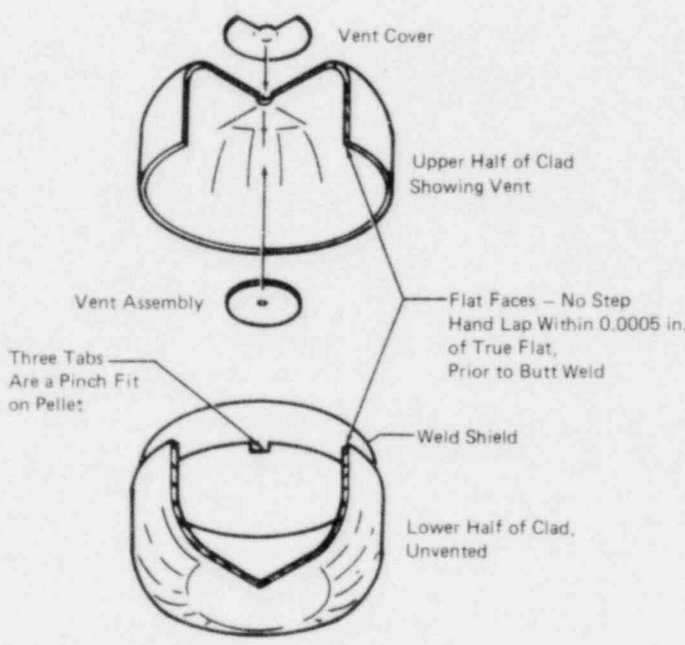


FIGURE 6 - Pellet clad capsule.

2.1.3 THERMAL INSULATOR

Thermal insulation of the GPHS fuel capsule is provided by the two layers of pyrolytic graphite (PG) shown in Figure 4. Lap joints are incorporated in each PG layer to eliminate the possibility of direct radiation from the impact shell to the capsule during thermal excursions.

2.1.4 IMPACT MEMBER

Impact protection for the GPHS fuel capsule is provided by a three-dimensional carbon-carbon composite shell [fine weave, pierced fabric (FWPF)], shown in Figure 4. The shell consists of three pieces, a body, a cap, and a separator. The impact shell wall thicknesses of the side and the corner were determined by impact experiments, and they defined the end-wall thickness. It was necessary to weaken the end wall so that it would crush on impact, hence the holes in the ends and in the separator. The location of the closure was also chosen on the basis of tests, which showed that the one-piece body resisted 45° impacts better than two or three piece body designs. The FWPF was chosen because its high density and unique character give good impact response, and it tends to stay in place to protect against secondary impacts or post-impact thermal environments.

2.1.5 REENTRY MEMBER

The GPHS reentry member, shown in Figure 4, is also made of FWPF. The material was chosen for its high resistance to thermal stress fracture and its good thermal ablation response. The reentry member design features an internal "window" that both reduces the weight and the reentry thermal stress. The necessary face and side wall thicknesses were determined from calibrated calculations by Battelle Columbus Laboratories. The details of the closure were based on reentry ablation experiments that indicated the need for a capped thread and on thread shear tests that defined the thread form.

2.1.6 LOCK MEMBER

The module stack is located by means of ORNL N2M bulk graphite keying members that also resist intermodule shear caused by vibration.

2.2 Accident condition evaluation

The GPHS module was designed to survive with no release of plutonium the launch, reentry, and impact conditions of a space mission. These conditions are significantly more severe than the hypothetical accidents of transportation. Enclosed is a letter from S. E. Bronisz (LASNL) to Dr. E. Johnson (Mound) discussing some of those impact tests.

FSA Aging Temperature	1330°C
FSA Aging Time	100 hr
Reentry Heat Pulse Temperature	1500°C
Reentry Heat Pulse Time	2 min
Impact Velocity	267 FPS
Impact Temperature	1430°C

University of California
LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545 505/667-5061

In reply refer to: CMB-5-C-79-1085
Mail stop: 730

December 18, 1979

Dr. E. W. Johnson
Monsanto Research Corporation
Mound Facility
P. O. Box 32
Miamisburg, Ohio 45342

Dear Dr. Johnson:

The General-Purpose Heat Source (GPHS) is required to survive the severe thermal and mechanical environments associated with atmospheric reentry and earth impact without releasing fuel, to be stable in the normal storage and shipping environments, and to survive any accident environments that might occur during ground handling. The philosophy applied to the project was that the design would be defined in an iterative process that would allow test results to guide the design during the development phases.

The design requirements have been met. The GPHS module will survive the possible reentry trajectories, according to the test-calibrated calculations of Battelle Columbus Laboratories. It will survive 58 m/s impacts against steel in any orientation at temperatures above 800°C. We will subject it to those fires, explosions, and fragment impacts that would accompany possible launch accidents.

The materials selected are all stable and compatible under normal storage and shipping conditions.

We do not intend to do any specific tests to demonstrate the survival of the GPHS in the accident environments that might occur during ground handling, because these environments are significantly less severe than the launch, reentry, and impact conditions to which we have or will test.

Yours truly,

S. E. Bronisz

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xc: R. Morrow, DOE
R. Mulford, CMB-5
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TWX 910-988-1773 Telex 66-0496 Fascimile 505/667-6937 (automatic) 505/667-7176 (operator assist)

3 Internal pressure capability and package standards evaluation

3.1 Internal pressure capability

3.1.1 GENERAL

Because the SSC is responsible for complete secondary containment of the heat source, only the internal pressure capability of the SSC will be considered. Figure 3 shows the basic configuration of the SSC.

3.1.2 METHOD

An SSC was modified to accept a 0 to 300 psig Ashcroft gauge and an inlet for the introduction of high pressure water. The totally welded SSC was then hydrostatically tested.

3.1.3 RESULTS

The pressure was raised in four distinct increments (0 to 50, 50 to 100, 100 to 150, and 150 to 200 psig). After reaching each plateau, the pressure was held constant for 5 min. Soon after the pressure passed 200 psig (approximately 205 psig), the top and bottom of the SSC started bulging. The pressure was slowly raised to 225 psig and then released.

ASME standards require a vessel to be pressure tested to 150% of design pressure. Under that ASME criteria, the SSC has an internal pressure capacity of 133 psi (200/1.50 = 133).

3.2 Package standards evaluation

3.2.1 GENERAL

In Part II of DOE 0529 [1], general standards are specified for materials, closures, lifting devices, and tie-down devices in addition to structural standards pertaining to load resistance and external pressure. The purpose of this evaluation is to provide the necessary supporting information which verifies that the GPHS module shipping container is in compliance with these standards.

3.2.2 MATERIALS

The packaging materials and the package contents will not cause any significant reactions even at hypothetical accident conditions. Design materials were carefully selected.

3.2.3 CLOSURES

Positive closures, utilizing several bolts to prevent inadvertent opening, are used on both the carrier and the finned cask.

3.2.4 LIFTING DEVICES

It is required that lifting devices that are an integral part of the package be capable of lifting three times the weight of the package and any attachments without generating stress in any material of the package in excess of its yield strength. The four shoulder eyebolts on the cover of the finned cask were tested and evaluated, and the carrier baseplate was evaluated with respect to this requirement.

It was verified that the cover eyebolts satisfy this requirement by simply lifting the entire shipping package using only one of the four eyebolts. This not only verified the eyebolts but also the bolts holding the cask cover to the cask body. Because the eyebolts are in place to lift the cask cover from the cask body and not the entire shipping package, this test was significantly more severe than normal usage. The calculated weight of the cask cover is 95 lb. The weight of the entire package during the test was 1010 lb. The one bolt was therefore supporting more than 10 times the weight expected. Figure 7 shows the test. Upon completion of the test, the eyebolt and bolts holding the cask cover to the cask body were removed and inspected. Figures 8 and 9 show that there was no damage to either bolt. The holes these bolts fit into were also examined with a flashlight, and no damage was observed. This test was performed after the entire package had been subjected to the hypothetical accident test.

The entire container is lifted using a forklift or hand pallet truck. Sections of 6 in. angle are welded to the bottom of the carrier base plate to provide access from two sides as seen in Figure 10. When the container is lifted, the maximum stresses will occur in the baseplate as the result of potential bending. The maximum gross weight of the container is 1200 lb (conservative), of which 950 lb is the maximum cask weight, and 250 lb is the maximum cage weight.

The yield strength of the plate material is 27,000 psi per ASME Pressure Vessel Code [2]. For this anaysis, three times the package weight (3 x 1200 = 3600 lb)

FIGURE 7 - Lifting test.

FIGURE 8 - Eyebolt after test.

FIGURE 9 - SSC cover bolt after test.

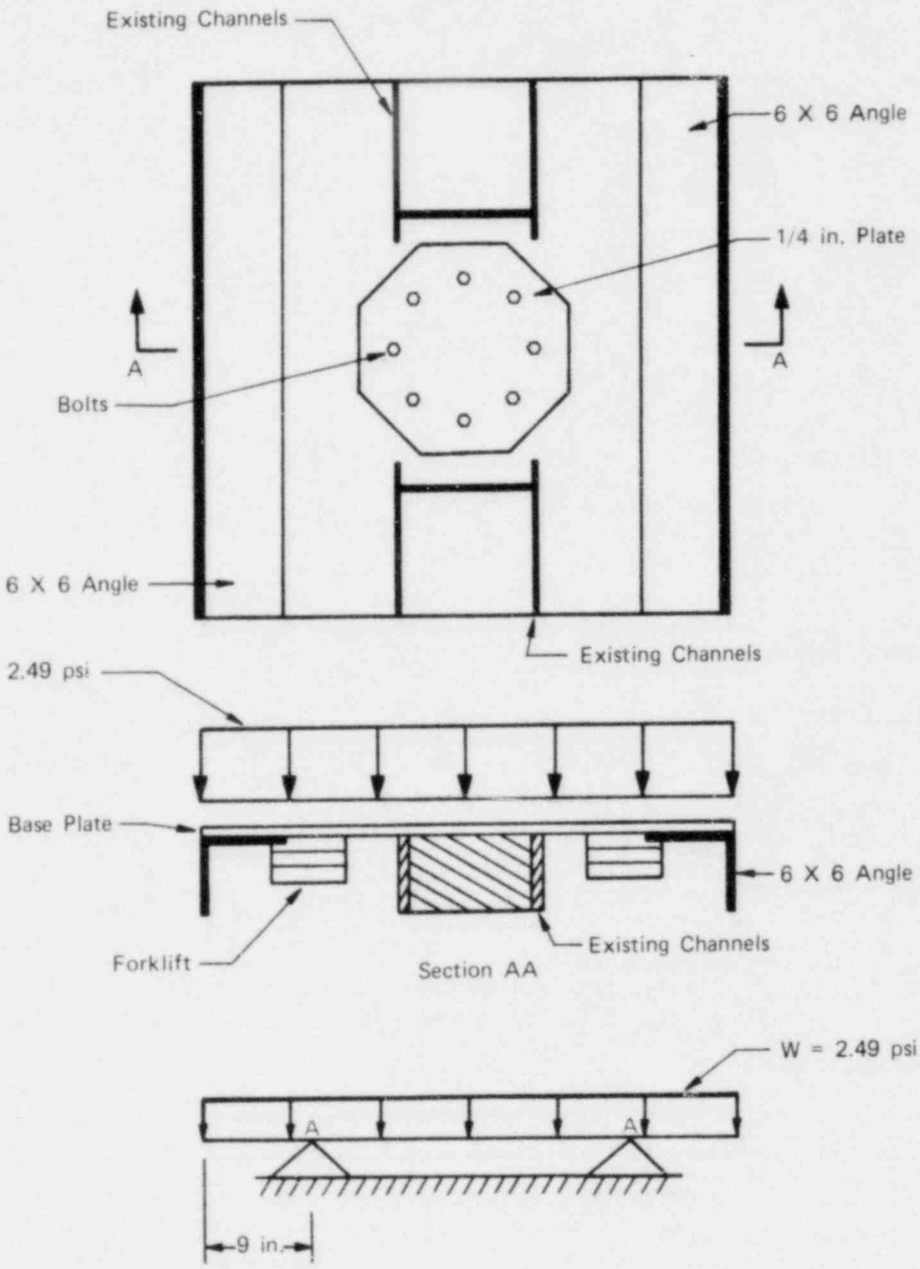

FIGURE 10 - Baseplate lifting evaluation.

is assumed to be uniformly distributed over the baseplate area. Thus

$$P = \frac{\text{Weight}}{\text{Area}} = \frac{3600}{(38)(38)} = 2.49 \text{ psi.}$$

If we consider a 1-in. wide strip through the center of the plate, as shown in Figure 10, the maximum bending moment, which occurs at point A, is

$$M_{max} = \frac{(2.49)(9)^2(1)}{2} = 100 \text{ in.-lb}$$

where the distances are as illustrated in Figure 10. The maximum plate bending stress is then

$$S_{max} = \frac{6M_{max}}{bt^2} = \frac{6(100)}{(1)(0.5)^2} = 2420 \text{ psi.}$$

The maximum bending stress is only 9% of the yield stress of the material which is 27,000 psi. Furthermore, this is a conservative result because the supports are not actually point supports, but are 10 in. wide.

3.2.5 TIEDOWN DEVICES

DOE Manual Chapter 0529 [1] specifies that tiedown devices that are a structural part of the package must be capable of withstanding simultaneously 10-g longitudinal, 5-g lateral, and 2-g vertical loads without exceeding the yield strength of the material. This requirement is applied to the eight cask-mounting bolts used to secure the finned cask to the carrier baseplate and is based on postulating that failure of the bolts under severe load could breach the cask; although this type of failure would not cause any loss of the radioactive materials. Since the carrier baseplate and the eight bolts attached to the carrier framework are not structural parts of the package, a RDT standard [3] is applied to these components. The RDT standard states that all parts of the tiedown system that are not considered structural parts of the package be so designed and fabricated that static stresses would not exceed the yield strength if the package were subjected to a sustained acceleration of 2 g forward or backward, 1 g sideways, or 2 g vertically. It is shown in this section that the GPHS shipping container satisfies the applicable requirements set forth in DOE Manual Chapter 0529 and in the RDT standard. Failure of the devices under excessive load will not impair the ability of the package to meet the requirements of the other general standards.

The bolts securing the finned cask to the carrier base plate are evaluated first. The mounting configuration is illustrated in Figure 11, which shows the eight bolts, designated 1 through 8. Inertia loads will cause tension in the mounting bolts which, in turn, causes bending stresses in the carrier baseplate. There are two methods of evaluating the bolts that hold the finned cask to the shipping cage. They are the "tipping" of the finned cask about bolt #3, and the "tipping" of the finned cask about the midplane (bolts #1 and #5) of the finned cask. Both possibilities were analyzed with the most conservative (the latter) being presented below. In the following evaluation, the maximum inertia load of a mounting bolt is found to be 4140 lb.

The maximum stress in the baseplate is found to be 10,050 psi, which is 3% of the yield stress of the steel.

The simultaneous application of 10-g longitudinal, 5-g lateral, and 2-g vertical inerita loads is illustrated in Figure 12.

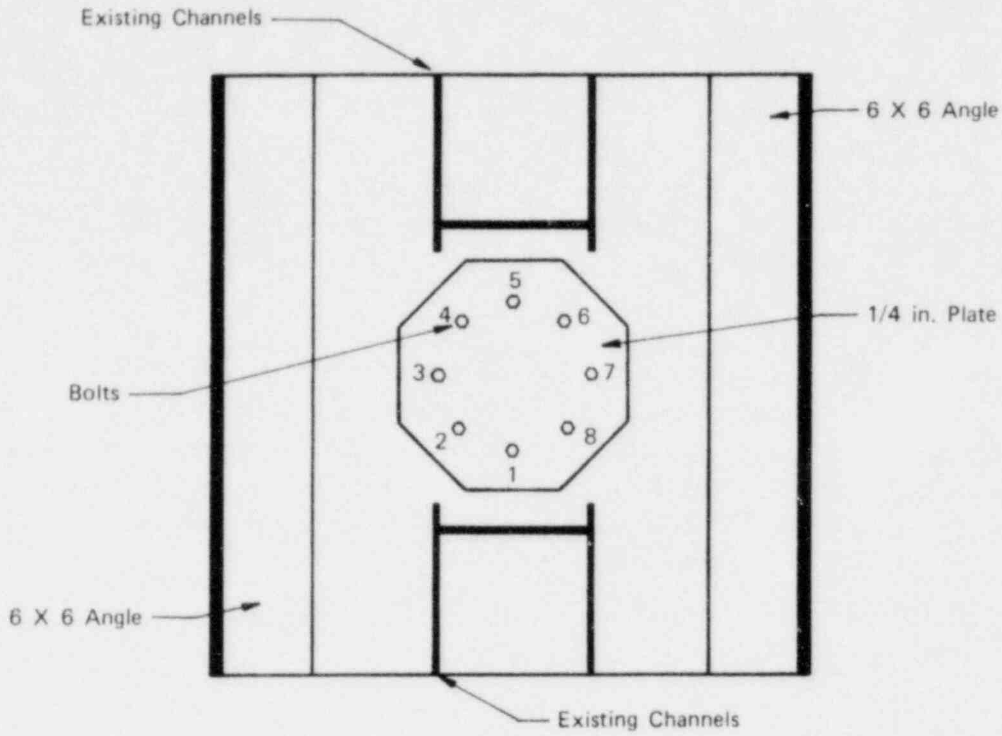

FIGURE 11 - Bolt mounting configuration.

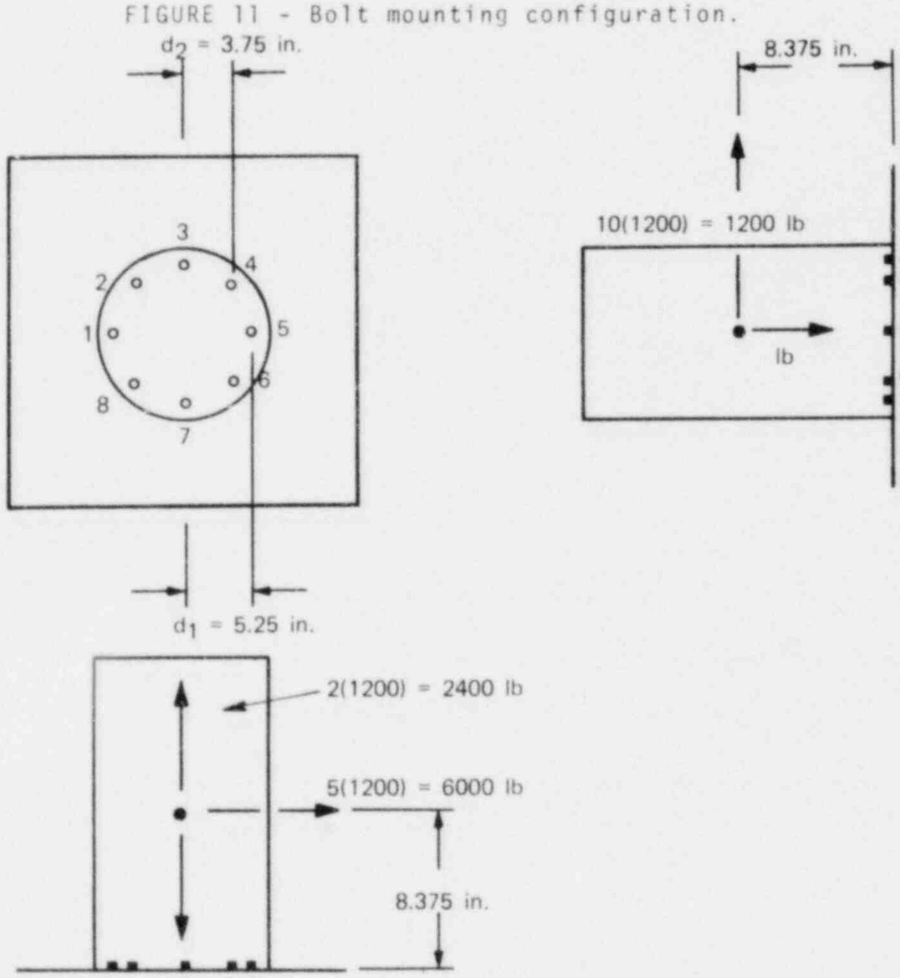

FIGURE 12 - Cask mounting inertia loads.

The maximum weight of the cask and its contents is 1,200 lb, and the distance between bolts is 3.75 in. Each of the inertia loadings specified above is first considered separately, and the results are then combined. The longitudinal inertia load of 10 g (10 x 1,200 lb = 12,000 lb) will cause compression stresses in bolts 2, 3, and 4, tension stresses in bolts 6, 7, and 8, and no pressure in bolts 1 and 5.

The magnitude of these bolt loads (P) can be found by summing around each bolt (see Figure 12).

Weight of cask = 1,200 lb

Longitudinal = 10 g = 12,000 lb

Lateral = 5 g = 6,000 lb

Vertical = 2 g = 2,400 lb

$\overline{Y}$ = distance to center of gravity from base plate = 8.375 in.

d_1 = 5.25 in.

d_2 = 3.75 in.

I = effective moment of inertia =

$$(1 \cdot d_{1,}{}^2 + 2 \cdot d_2{}^2) \cdot 2$$

$$= \left[(5.25)^2 + 2 \cdot (3.75)^2\right] \cdot 2 = 111.00$$

Longitudinal

$$M = (10\ g)\ \overline{Y} = 100,500 \text{ in.-lb}$$

$$P_7 = \frac{M \times d_1}{I} = \frac{(100,500)(5.25)}{111.00} = 4750 \text{ lb}$$

$$P_{8+6} = \frac{M \times d_2}{I} = \frac{(100,500)(3.75)}{111.00} = 3400 \text{ lb}$$

The negative sign indicates compression. Therefore,

$P_1 = 0$

$P_2 = -3,400$ lb

$P_3 = -4,750$ lb

$P_4 = -3,400$ lb

$P_5 = 0$

$P_6 = 3,400$ lb

$P_7 = 4,750$ lb

$P_8 = 3,400$ lb

Next, the lateral inertial loading of 5 g (6,000 lb) is considered. For this loading, bolts 1, 2, and 8 are in compression, bolts 4, 5, and 6 are in tension, and bolts 3 and 7 are under no pressure.

Lateral

$$M = (5\ g)(\overline{Y}) = 50,250$$

$$P_5 = \frac{M \times d_1}{I} = \frac{(50,250.)(5.25)}{111.00} = 2,380 \text{ lb}$$

$$P_{4+6} = \frac{M \times d_2}{I} = \frac{(50,250.)(3.75)}{111.00} = 1,700 \text{ lb}$$

The negative sign indicates compression. Therefore,

$P_1 = -2,380$ lb

$P_2 = -1,700$ lb

$P_3 = 0$

$P_4 = 1,700$ lb

$P_5 = 2,380$ lb

$P_6 = 1,700$ lb

$P_7 = 0$

$P_8 = 1,700$ lb

Finally, the vertical loading of 2 g is considered. Here the weight of the cask is included in the analysis, and the resulting vertical loading becomes 2 g - 1 g = 1 g = 1,200 lb. For this loading condition, each bolt will develop tensile stresses of equal magnitude. Equilibrium in the vertical direction requires:

$P_1 = P_2 = P_3 = P_4 = P_5 = P_6 = P_7 =$

$P_8 = 1{,}200/8 - 150$ lb

The three inertia loads determined above for each bolt are added together ($P_1 = 150 - 2{,}380 + 0 = -2{,}230$ lb) to obtain the resultant bolt forces as follows:

$P_1 = -2{,}230$ lb

$P_2 = -4{,}950$ lb

$P_3 = -4{,}600$ lb

$P_4 = -1{,}550$ lb

$P_5 = 2{,}530$ lb

$P_6 = 5{,}250$ lb

$P_7 = 4{,}900$ lb

$P_8 = 1{,}850$ lb

Thus, the maximum bolt load is 5,250 lb. Since each bolt is 1/2 in. nominal diameter with a minimum cross-sectional area of 0.1257 in.^{2}, the maximum tensile stress developed in the bolt is:

$$S_{max} = \frac{P_{max}}{A} = \frac{5{,}250}{0.1257} = 41{,}800 \text{ psi}$$

This is only 35% of the 120,000 psi tensile strength of the bolts. The bolts, therefore, satisfy DOE M0529 requirements as well as the RDT standards.

The RDT standard for nonstructural parts is applied to the carrier baseplate. The requirements are satisfied if the stresses are less than the material yield stress when a longitudinal inertia loading of 2 g is applied, since the lateral and vertical loads will cause less stress than the longitudinal load.

$$\text{Stress} = F \cdot h/(bt^2/6)$$

F = force applied = 2 g = 2,400 lb

h = height above base plate force applied = 8.375 in.

t = thickness of base plate = 0.5 in.

b = distance along base plate which force is transferred to = 38 in.

$$\text{Stress} = \frac{(2{,}400)(8.375)}{\frac{(38)(0.5)^2}{6}} = 12{,}700 \text{ psi}$$

Since this value is only 47% of the material yield stress, which is 27,000 psi, the RDT standard is satisfied.

Next is an evaluation of the tiedown system which is comprised of the eight rings fastened to the carrier framework and is used to secure the shipping container in the transport vehicle with chains or cables. It is assumed that (1) the container itself if perfectly rigid, (2) the cross-sections of all cables are identical, and (3) the center of mass coincides with the centroid of the cask. The maximum gross weight of the container is 1,200 lb. The maximum cable load is shown below to be 703 lb, and the resulting stress is 440 psi. Since this is only 1.6% of the yield stress, the RDT standard is satisfied.

The cable tiedown configuration for the carrier is shown in Figure 13. The RDT standard requires that the stresses developed in the carrier framework be less than the material yield stress when an inertia load of 2 g is applied longitudinally, when an inertial load of 1 g is applied laterally, or when an inertial load of 2 g is applied vertically. Since the vertical load requirement obviously causes less stress than the other two loads, no calculations are necessary for the vertical case. The inertial loading conditons are shown in Figures 14 and 15. The longitudinal load of 2 g, shown in Figure 14, is

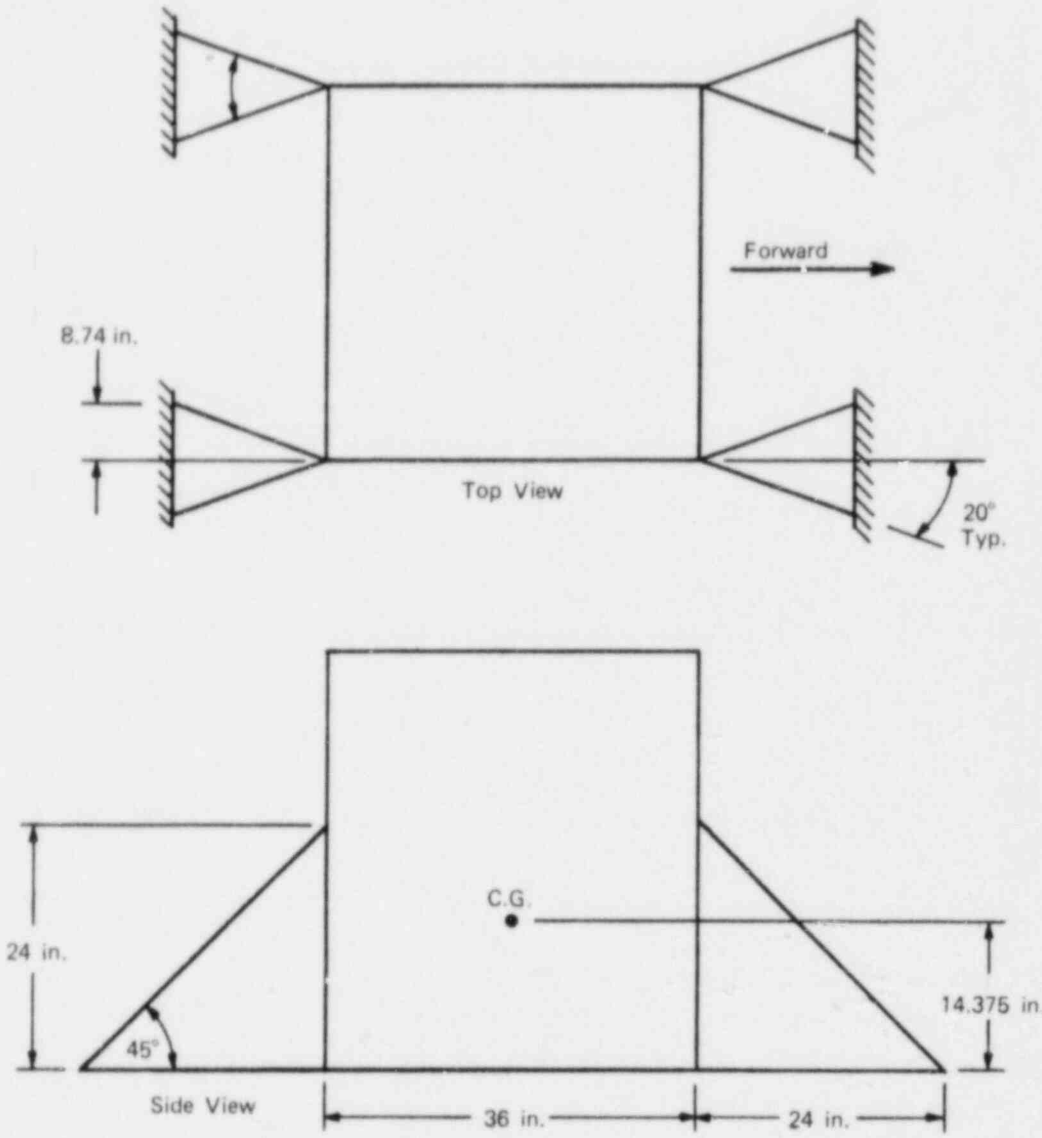

FIGURE 13 - Carrier tiedown.

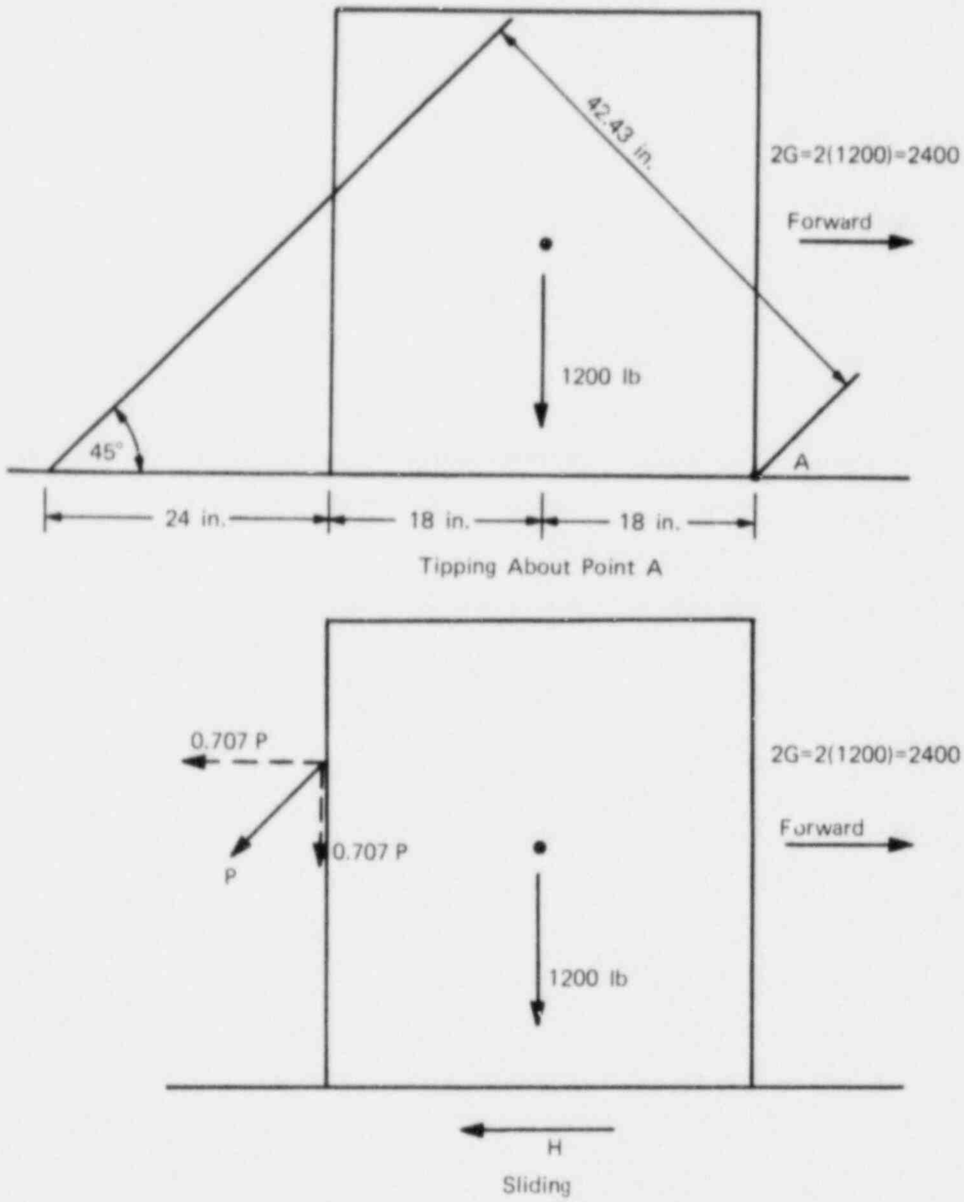

FIGURE 14 - Longitudinal tiedown inertia loads.

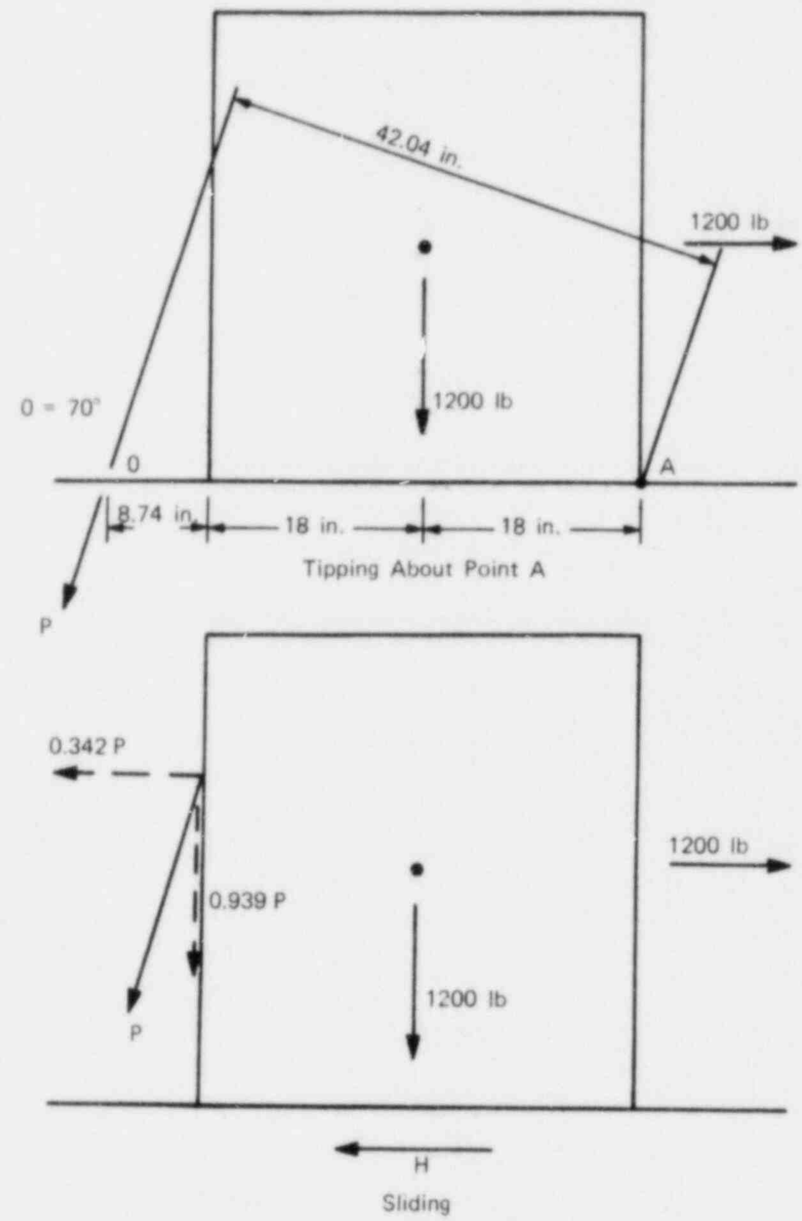

FIGURE 15 - Lateral tiedown inertia loads.

considered first. Since chocking is used to prevent slipping of the container along the transport vehicle floor, the container will tend to overturn about point A. To determine the cable loads for this condition, moments are summed about point A as follows:

$$P(42.43 \text{ in.}) + 1{,}200 \text{ lb } (18 \text{ in.}) = 2{,}400 \text{ lb } (14.375 \text{ in.})$$

$$P = 305 \text{ lb}$$

The force (P) acting on the four cables, labeled 1 through 4 in Figure 13, is shown in Figure 14. Each cable load (F) is then

$$F = \frac{(305/4)}{\cos 20°} = 80 \text{ lb}$$

If it is assumed, conservatively, that no chocking is used, the cable forces developed if the container were free to slide along the floor may be determined. This condition is shown in Figure 14. Equilibrium in the horizontal direction requires that

$$2 g = H + 0.707 P = 2{,}400 \text{ lb}$$

where P is the cable load, and H is the frictional force along the vehicle floor, as shown in Figure 13. A value of 0.4 for the coefficient of friction between the floor and the carrier is used to calculate the frictional force (H)

$$H = 0.4(0.707P + 1{,}200 \text{ lb}) = 0.28P + 480$$

Substituting this into the above equation yields

$$0.28P + 480 + 0.707P = 2{,}400 \text{ lb}$$

Thus, P = 1,945 lb, where P representes the total load on all four cables. Each cable load is then

$$F = \frac{(1945/4)}{\cos 20°} = 520 \text{ lb}$$

In a similar manner, the cable loads are determined when a lateral inertia ioad of 1 g is applied to the carrier as shown in Figure 15. With chocking, the carrier will tend to rotate about point A. To determine the cable loads, we sum moments about point A as follows:

$$P(42.04 \text{ in.}) + 1{,}200 \text{ lb } (18 \text{ in.}) = 1{,}200 \text{ lb } (24 \text{ in.}) \quad .$$

The equation yields P ≈ 170 lb. The load in one cable is

$$F = \frac{(170/4)}{\sin 20°} = 125 \text{ lb}$$

If it is conservatively assumed that no chocking is used and the container will slide along the floor, equilibrium in the horizontal direction requires that

$$0.342P + 0.342P + H = 1{,}200 \text{ lb} \quad ,$$

where H is the frictional force along the floor and P represents the cable forces. Using 0.4 for the coefficient of friction gives the frictional force along the floor (H) as

$$H = 0.4\ (0.939P + 0.939P + 1200) \quad ,$$

$$H = 0.75P + 480$$

Substituting this into the earlier equation yields

$$0.342P + 0.342P + 0.75P + 480 = 1{,}200$$

Thus,

$P = 500$ lb

The load in one cable is

$$F = \frac{(500/2)}{\sin 20°} = 735 \text{ lb}$$

From the analysis above, it is determined that the maximum cable load developed for the required inertia loading condition is 735 lb. The framework of the carrier consists of 2 x 2 x 3/8 in. steel angle iron. The eight tiedown rings are secured to the framework, and cables are attached to the rings. Since each tiedown ring is rated at 4,000-lb load capacity, the rings clearly exceed requirements. The maximum compressional stress in the angle iron framework is determined next. The vertical component of the 735-lb load (F_v) is calculated as follows:

$$F_v = 735 \sin 70° = 690 \text{ lb}$$

The maximum compressive stress in the angle iron is

$$S_{max} = \frac{F_v}{A} = \frac{690}{(2 \text{ in.} + 2 \text{ in.})(0.375 \text{ in.})}$$

$$= 460 \text{ psi}$$

This stress is only 1.7% of the material yield stress, which is 27,000 psi, and the RDT standard is satisfied.

The results of the cask mounting and tiedown evaluations are summarized in Table 1.

3.2.6 LOAD RESISTANCE

When it is regarded as a simple beam supported at its end along any major axis, the shipping container must be capable of withstanding a static load, normal to and uniformly distributed along its length, equal to five times the fully loaded container weight without generating stresses in any material of the container in excess of the yield strength of that material.

The GPHS cask is illustrated in Figure 16. The cask material is 304 stainless steel with a minimum specified yield strength of 30,000 psi, per the ASME Pressure Vessel Code [2]. The maximum weight of the cask is 1,200 lb. Stresses in the cask resulting from the uniform load are determined, as recommended by Shappert [4], from the following equation:

$$S = MC/I = M/Z$$

Table 1 - RESULTS OF CASK MOUNTING AND TIEDOWN EVALUATIONS

Component	Criteria	Maximum Load (lb)	Maximum Stress (psi)	Material Yield Stress (psi)
Cask Mounting Bolt	RDT	5,250	41,800	(120,000 tensile)
Carrier Base Plate	RDT	2,400	12,700	27,000
Tiedown Ring	RDT	735	(Rated 4,000-lb load)	
Carrier Framework	RDT	690	460	27,000

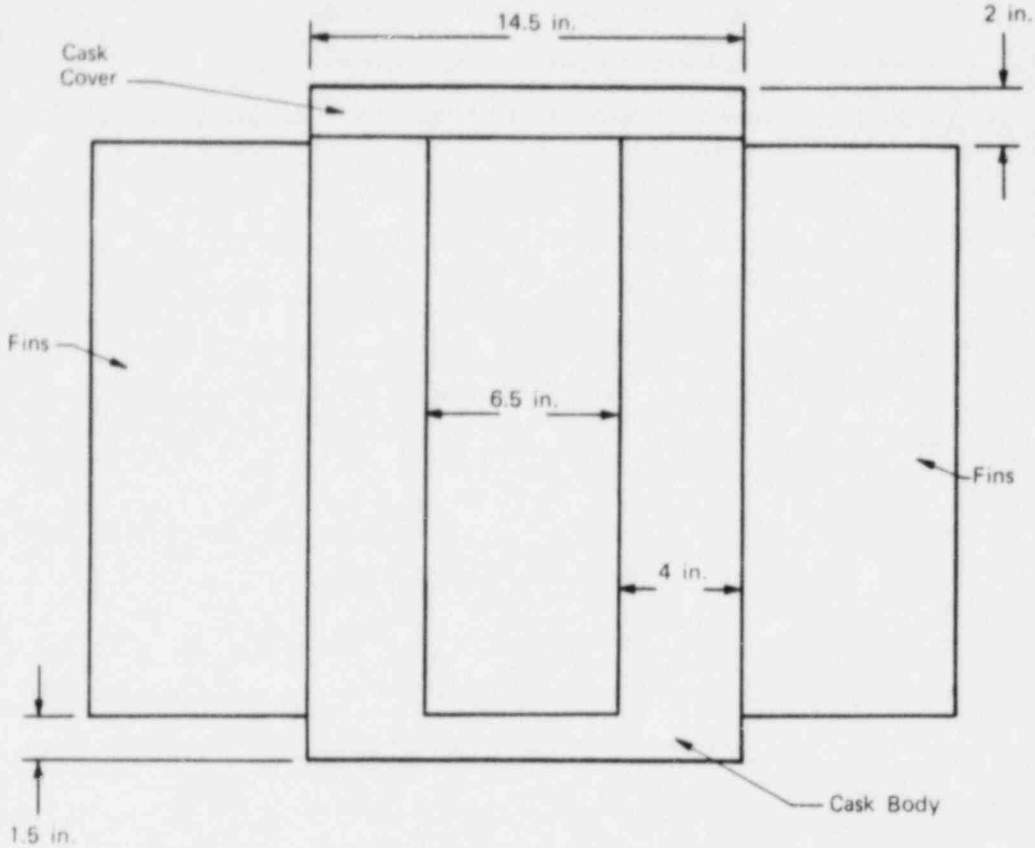

FIGURE 16 - Finned cask.

where

S = stress (psi),

M = maximum bending moment, $M = 5\ WL/8$ (in.-lb)

$Z = I/C$ = section modulus of cask

$= \frac{\pi}{4D_o}(D_o^4 - D_i^4) =$

$= \pi D_o^2\ t$ (in.^{3}) for a large diameter, thin-walled cylinder,

W = weight of cask, W = 1,200 lb,

L = length of cask, L = 18.75 in.,

D_o = outside diameter of cask, D_o = 14.5 in., and

t = effective thickness of cask wall, t = 4.00 in.

The computed maximum bending moment is

$$M = 5\ (1200)(18.75)/8 = 14{,}100 \text{ in.-lb.}$$

The computed section modulus is

$$Z = \pi D_o^2 t = \pi (14.50)^2\ (4.00) = 2{,}640 \text{ in.}^3$$

The maximum bending stress is then

$$S_{max} = 14{,}100/2{,}640 = 5.34 \text{ psi.}$$

Since this stress value is only 0.01% of the material yield stress of 30,000 psi, the GPHS cask satisfies the load resistance requirement.

3.2.7 EXTERNAL PRESSURE

The containment vessel must be capable of withstanding an external pressure of 25 psi without any loss of radioactive contents. Conservatively, it is assumed that no loss of contents will result if the allowable stress of the finned cask body material is not exceeded and if local buckling does not occur, even though these conditions would not necessarily cause the cask to be breached and would not affect the SSC, which are the containment vessels. The GPHS cask assembly is shown in Figure 16. It is constructed of 304 stainless steel with an allowable stress of 15,600 psi at 200°F (93°C). The wall thickness of the cask is 4 in. Also, it is assumed, conservatively, that no structural strength is provided by the cooling fins.

First, the maximum bending stresses in the cask cover and the circular bottom end plate are considered. The actual boundary condition of the circular bottom end plate lies somewhere between fixed and simply supported. The cover plate is bolted to the flanged body and is assumed to have simply supported edges. The bottom end plate is welded to the container body, and the edge is assumed, conservatively, fixed. The maximum bending stress in uniformly loaded circular plates is given by

$$S_{max} = 1.24\ R^2P/T^2, \text{ for simply supported (top cover plate)},$$

and

$$S_{max} = 0.75\ R^2P/T^2, \text{ for fixed edge (bottom plate)},$$

where

S_{max} = maximum bending stress (psi),

R = radius of plate, R = 7.25 in.,

P = pressure, P = 25 psi, and

T = thickness of plate,
T = 2.00 in. (top cover plate)
T = 1.50 in. (bottom plate) .

The maximum bending stress in the cover is then

$$S_{max} = 1.24\ R^2P/T^2 = 1.24\ (7.25)^2(25)/(2.00)^2 = 410 \text{ psi}$$

The maximum stress in the circular bottom end plate is:

$$S_{max} = 0.75\ R^2P/T^2 = 0.75\ (7.25)^2(25)/(1.5)^2 = 440 \text{ psi}$$

In the above cases, the maximum bending stresses in the material are only 2.8% of the allowable stress.

Second, the maximum membrane stress in the cask body is calculated. It is the hoop stress expressed as

$$S_{max} = PR/T,$$

where

S_{max} = maximum hoop stress (psi),

P = pressure, P = 25 psi,

R = radius of body, R = 7.25 in., and

T = Body wall thickness, T = 4 in.

Therefore,

$$S_{max} = 25(7.25)/4.00 = 45 \text{ psi}$$

This value is only 0.3% of the allowable stress.

The third consideration is the buckling strength. The allowable external pressure for the vessel is computed using the procedures specified in the ASME Pressure Vessel Code, Section VIII [2], which provides an extremely conservative value for the critical pressure.

The ASME pressure vessel code states that the allowable external pressure is given by the expression

$$P_{allowable} = 4B/(3D/t) = 1839$$

where

$P_{allowable}$ = the allowable pressure load of the vessel (psi),

D = diameter of vessel, $D = 14.5$ in.,

t = thickness of vessel, $t = 0.50$ in., and

B = constant depending on the ratios D/t and L/t (where L = length of vessel), $B = 10{,}000$.

4 Steady state temperature profile

4.1 Purpose

It is necessary to determine the steady-state temperature profiles of the shipping container and its contents to ensure compliance with DOE/DOT regulatory requirements.

4.2 Procedure and test method

Two Rite heat sources were stored in two unmodified SNAP-19 finned casks. The Rite I and II heat sources are rated at 820 and 420 W respectively. The Rite heat sources had been stored in the SNAP-19 casks for at least six months. Figure 17 shows the locations of the thermocouples.

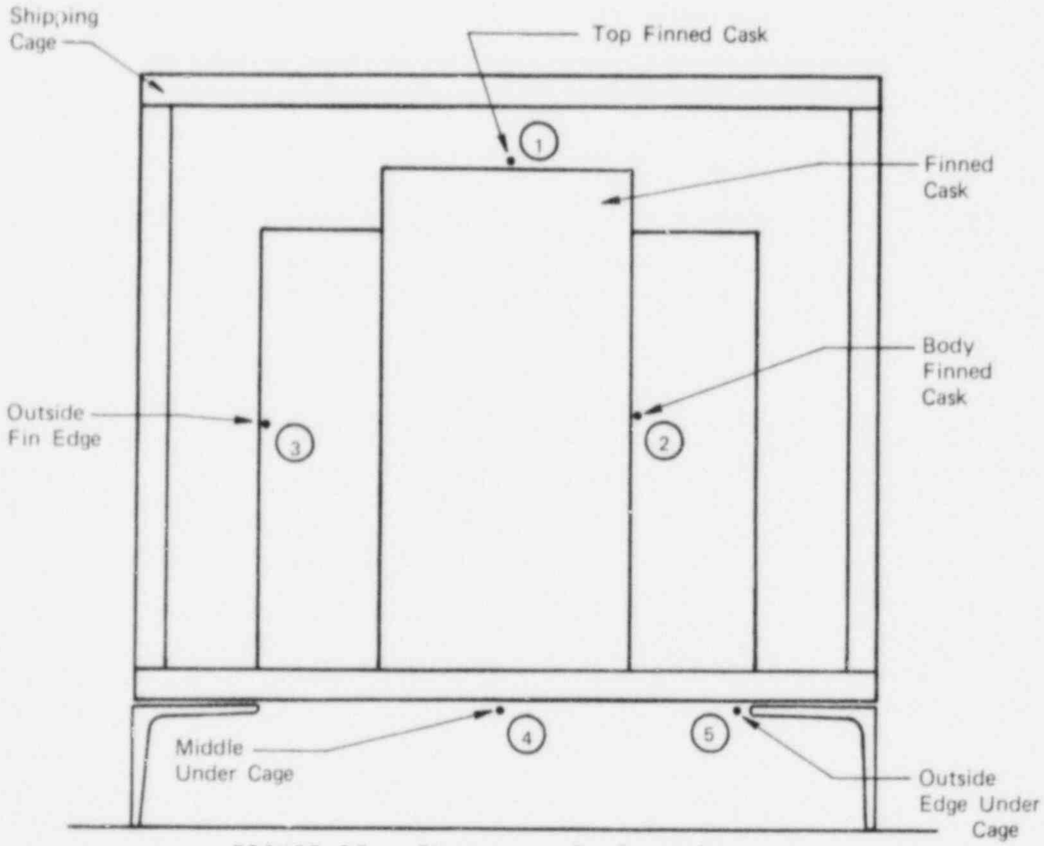

FIGURE 17 - Thermocouple locations.

The thermocouples were held in place by high thermal conductivity aluminum-filled two-part adhesive #1751, manufactured by 3M.

The temperature readings were taken in a large room (25 ft x 25 ft) with no other heat source present. Air movement was measured in the room prior to the arrival of the heat source. No erratic patterns were observed with the maximum velocity being 11 ft/min.

These measurements produced temperatures on the exterior of the shipping package but not in the interior of the SSC.

For the interior temperature of the SSC, a 500-W heating tape was installed in the SSC. The heating tape was attached to a variac manufactured by Staco, Inc., type 500-B, adjustable from 0 to 140 V, and a maximum of 7.5 A. A 0 to 300 psig pressure gauge by Ashcroft was welded to the top of the SSC. A K-type thermocouple was suspended approximately 1 in. from the lid of the SSC. The electrical and thermocouple feedthroughs were accomplished by using vacuum feedthroughs by Pave Technology Company (VS-12-SS-HTES-1-KT for the thermocouple and VS-12-SS-HTES-2-TEE for the electrical).

The power produced by the heating tape was measured by varying the voltage on the variac and reading the current using an ammeter.

The SSC with heating tape, thermocouple, and pressure gauge was placed in an 11-gal can (14-in. diameter and 16-1/2 in. high). Five and one-half inches of mineral fiber #BMW insulation was placed under the SSC with 4 in. around and 3-3/4 in top.

The insulation was placed around the SSC to produce conservative results in temperature and pressure.

This insulation produces an R value of 11 with 3-1/2 in. of material, and an R value of 19 with 5-1/2 in. of material.

4.3 Test results

Table 2 gives the measured, calculated, and corrected steady-state temperature results. Figure 18 is a graph of the 100°F ambient temperature profiles from the Rite I and II heat sources.

The maximum temperature of 146°F was observed at the finned cask top, while the body of the finned cask and outside fin edge had temperatures of 131°F and 126°F, respectively. The middle under the cage temperature was 127°F, and the outside edge temperature under the cage was 112°F. These temperatures were corrected to 100°F ambient air.

At first, the SSC inside the insulation was subjected to 50 V at 2 A (100 W). At 100 W, the temperature stabilized at 210°F with essentially no pressure rise.

The power was then increased to 187 (75 V and 2.5 A). The temperature and pressure stopped rising at 450°F and 11 psig. A final temperature and pressure of 608°F and 18 psig were realized at 300 W (100 V and 3 A).

4.4 Maximum heat load capability

The maximum heat load capability of this shipping package is 750 W and 250 W for each SSC. Because of the double containment standard required by NRC, the heat load capacity of this complete package is firm.

Table 2 - MEASURED, CALCULATED, AND CORRECTED TEMPERATURES AT DIFFERENT POSITIONS OF THE FINNED CASK WITH DIFFERENT HEAT SOURCES AND INSIDE SSC

	Measured Temp (°F)		Corrected to 100°F (°F)			Measured (°F)
	420-Rite I	820-Rite II	420-Rite I	820-Rite II	750-GPHS	300 W
Top Finned Cask	106	130	126	150	146°F	
Middle Side Body Finned Cask	98	114	118	134	131°F	
Middle Side Fin	93	104	113	126	124°F	
Middle Under Cage	95	108	115	128	127°F	
Outside Edge Under Cage	87	98	107	113	112°F	
Inside SSC						608°F

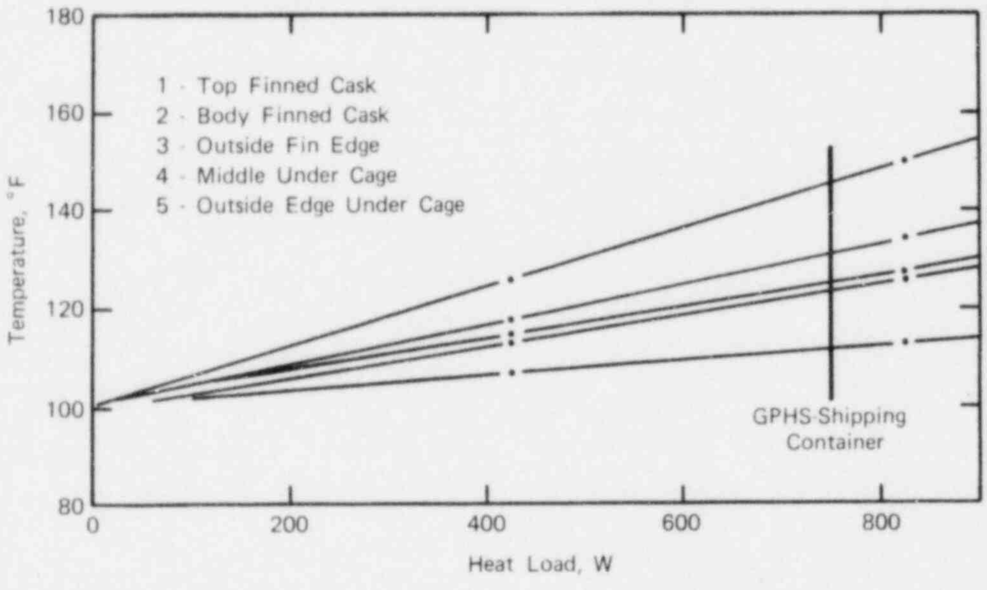

FIGURE 18 - Steady-state temperature profile.

5 Normal conditions of transport evaluation

5.1 General

DOE Manual, Chapter 0529, requires nuclear packaging to be capable of satisfactory packaging effectiveness and radioactive materials containment when subjected to the following nine tests simulating normal transportation environment and handling conditions:

1. Heat
2. Cold
3. Pressure
4. Vibration
5. Water Spray
6. Free Drop
7. Corner Drop
8. Penetration
9. Compression

The related testing and engineering evaluations described in this section adequately demonstrate that the nuclear packaging requirements are satisfied.

5.2 Heat

Direct sunlight at an ambient temperature of 130°F (54°C) in still air would not increase the temperatures of the packaging or the primary containment vessels in excess of design capabilities.

It is not likely that the GPHS module shipping container would ever be stored for any length of time in direct sunlight at 130°F (54°C). For a complete evaluation, however, the temperatures resulting from this condition are estimated. Shappert's approach establishes the average solar heat load over a 24-hr period as 42 W/ft^2 of projected surface area. The projected area consists of the top surfaces of the finned cask and fins, which are exposed to sunlight shining normal to the shipping container. For simplicity, the shading effect of the mesh carrier cap is ignored. The exposed area is calculated as follows:

$$A = \underbrace{\frac{\pi(14.5)^2}{4(144)}}_{\text{Cover diam}_2} + \frac{\overset{\text{fins}}{80}\ \overset{\text{(thickness)}}{(0.125)}\ \overset{\text{(exposed length)}}{(5.5)}}{144}$$

$$A = 1.53\ ft^2$$

Therefore, the solar heat load (Q_s) is

$$Q_s = (1.53\ ft^2)\ (42\ W/ft^2)$$

$$Q_s = 64.3\ W$$

The temperature increases that are produced by the additional 64.3-W heat load are added to the experimentally determined temperatures, produced by the contents, to determine the resulting temperatures. The calculations are linear interpolations/extrapolations of the temperatures reported in the Steady-State Temperature Profiles section of this report. The results are summarized in Table 3 .

Thus, the heat input from the sun is not expected to increase the cask temperature at any location by more than 4°F. Even with a 4°F increase, the package is well within all design specifications.

5.3 Cold

An ambient temperature of -40°F (-40°C) in still air and shade will not decrease the effectiveness of the packaging. It would reduce the temperature profile within the package and possibly would be beneficial.

5.4 Pressure

Reduced atmospheric pressure of 0.5 times standard atmospheric pressure is well

Table 3 - TEMPERATURES AT KEY LOCATIONS IN SHADE AT 100°F AND IN DIRECT SUNLIGHT AT 130°F (54°C)

Location	Temperature[a] In 100°F Shade (°F)	Temperature Correction For 64.3-W Solar Load (°F)	Temperature[a] in 130°F Sun (°F)
Top Finned Cask	146	4	150
Body Finned Cask	131	3	134
Outside Fin Edge	126	2	128
Middle Under Cage	127	2	129
Outside Edge Under Cage	112	1	113

[a]For 750-W container.

within the capability of the SSC which is what secondary containment is based on. Upon completion of the hypothetical accident tests (30-ft drop, fire, water immersions) the four SSCs involved were helium leak tested. Each SSC was separately placed in a bell jar which was than evacuated to less than one torr. No leaks were detected in the SSCs.

5.5 Vibration

Vibration normally incident to transport will not reduce the effectiveness of the packaging. This is illustrated by the two 30-ft drops that the entire shipping package and an SSC survived.

5.6 Water spray

A water spray sufficiently heavy to keep the entire exposed surface of the package, except the bottom, continuously wet during a period of 30 min will not damage the finned cask in any way or have any effect, other than cooling, on the contents of the GPHS module. The shipping container is actually exempt from this test requirement since it is all-metal construction.

5.7 Free drop

A free drop through a distance of 4 ft onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected, would not substantially reduce the effectiveness of the packaging. This test would damage the steel mesh carrier cap. However, since the finned cask and SSC were not damaged during two 30-ft drops, it is doubtful that any damage would occur in a 4-ft drop.

5.8 Corner drop

This test requires a free drop onto each corner of the package in succession or, in the case of a cylindrical package, onto each quarter of each rim, from a height of

1 ft onto a flat, essentially unyielding horizontal surface. This test applies only to packages that are constructed primarily of wood or fiberboard and do not exceed 110 lb gross weight, and to all Fissile Class II packagings.

This test is not applicable to the GPHS heat source shipments in the shipping container, because the packaging is of metallic construction, weighs approximately 1200 lb, and the shipments are Fissile Class I.

5.9 Penetration

It is necessary to evaluate the impact of the hemispherical end of a vertical steel cylinder, 1-1/4 in. in diameter, weighing 13 lb, and dropped from a height of 40 in. onto the exposed surface of the package that is expected to be most vulnerable to puncture.

This test could cause minor damage to the steel mesh carrier cap, but it is unlikely that it would damage the finned cask, and it would have no effect on the SSC. Assuming, conservatively, that the steel mesh has no effect on slowing down the steel cylinder and that the cylinder could somehow strike the 1.5 in. thick bottom plate of the cask (thinnest area), the steel cylinder would not penetrate the finned cask. This is shown by comparing the kinetic energy of the cylinder on impact with the energy required to shear the bottom. The kinetic energy is equal to the potential energy of the 13-lb cylinder at a height of 40 in. and is calculated as follows:

$$KE = PE = \left(\frac{40 \text{ in.}}{12 \text{ in./ft}}\right)(13 \text{ lb}) = 43 \text{ ft-lb}$$

The Machinery Handbook [5] gives the equation for calculating the energy required to shear the cask body wall as follows:

$$E_p = F_{su} (\pi Dt) (t)$$

where E_p = the energy required to shear the cask wall (ft-lb),

F_{su} = ultimate shear strength of 304 stainless steel at 200°F (60% of tensile), F_{su} = 45,000 psi,

D = diameter of potential hole, D = 1-1/4 in., and

t = cask bottom thickness, t = 1.5 in.

The factor (πDt) is the potential shear area of the hole. Substitution into the above equation yields

$$E_p = (45,000) (\pi \times 1\text{-}1/4 \times 1.5) (1.5) \left(\frac{1 \text{ ft}}{12 \text{ in.}}\right)$$

$$E_p = 33,100 \text{ ft-lb.}$$

Thus, the required energy is nearly 770 times as great as the energy available, and the cask bottom would not be penetrated.

5.10 Compression

This test requires a compressive load equal to either five times the weight of the package or 2 psi multiplied by the maximum horizontal cross section of the package, whichever is greater. The load must be applied during a period of 24 hr, uniformly against the top and bottom of the package in the position in which the package would normally be transported.

The evaluation is based on a load of 5,800 lb, which is five times the maximum gross weight of the package since the alternate criteria yields a value of only 330 lb. The strength of the carrier cap is neglected for simplicity. The finned cask body is illustrated in Figure 19. The wall thickness (t) is actually 4 in., except where the grooves have been machined for secure attachment of the fins. The effective wall thickness is, conservatively, taken to be 3-7/8 in. and the effective outside diameter of the cask is 14.5 in.

The longitudinal compressive stress (S) is calculated by dividing the load by the cross-sectional area of the cask wall as follows:

$$S = 5,800/\pi Dt$$

where D is the diameter and t is the wall thickness.

The result is

$$S = 5,800/\pi(14.5)(3.875)$$

$$S = 33 \text{ psi.}$$

The stress value is only 0.2% of the allowable stress, which is 15,600 psi for 304 stainless steel at 200°F (93°C).

The critical buckling stress of the cylindrical shell when subjected to uniform axial compression is calculated to determine the ultimate capability of the cask. The critical buckling stress (S_{cr}) is given by the following equation:

$$S_{cr} = \frac{Eh}{R\sqrt{3(1-\mu^2)}}$$

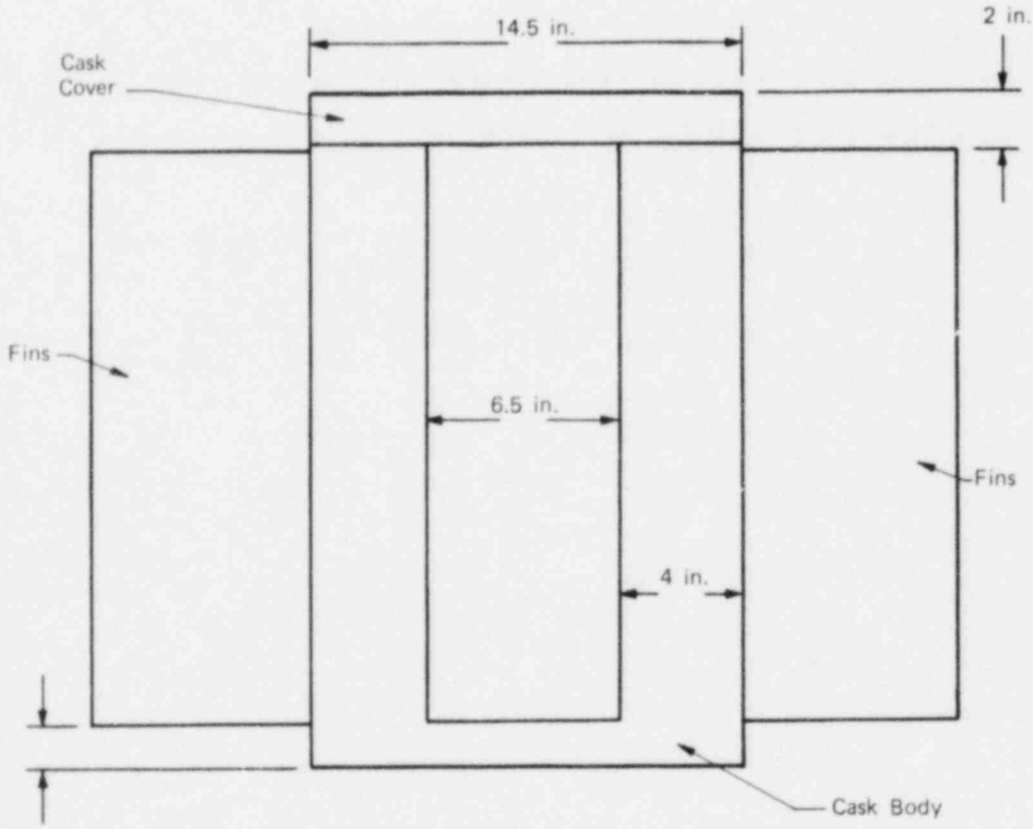

FIGURE 19 - Finned cask.

where

E = modulus of elasticity,

$E = 30 \times 10^6$ psi,

h = cask thickness, $h = 3.875$ in.,

R = radius of cask, $R = 7.25$ in.,

and

μ = Poisson's ratio, = 0.3.

Thus, the critical buckling stress is:

$$S_{cr} = \frac{30 \times 10^6 (3.875)}{7.25\sqrt{3(1-0.09)}} = 9.7 \times 10^6 \text{ psi.}$$

This value for the ultimate capability is nearly 300,000 times greater than the longitudinal compressive stress in the cask calculated above. Thus, placing a 5,800-lb load on the top of the fined cask would not damage the finned cask and would have no effect on the SSC.

6 Hypothetical accident test

6.1 General

In DOE 0529, criteria are established for hypothetical accident tests which the shipping package must pass. These tests are a 30-ft drop, puncture test, fire test, and water immersion. This section covers those tests.

6.2 Free drop

This test requires a free drop through a distance of 30 ft onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected.

There were two sections to this test. One involved the entire package (SSC finned cask, shipping cage), and the other tested the stainless steel can (SSC). Both "packages" were dropped twice from a height of 30 ft.

Figure 20 shows steel wool being placed around the last SSC in the finned cask. The entire package was first dropped upside down on a corner, as is depicted in Figures 21 and 22. It can be seen in Figure 23 that the top of the finned cask did not touch the ground. Figure 24 shows the overall damage to the shipping cage.

Figure 25 illustrates that, in the second drop, the entire package was upright with a leading corner. The package landed on its left rear corner, bounced to the right front corner, and then settled back on the left rear corner. Figures 26, 27, and 28 depict this.

The damage after two 30-ft drops can be seen in Figure 29. Note that there was no damage to the finned cask. Figure 30 shows the bolts still intact and the damage to the bottom angle. The corner not in the photograph is damaged in the same manner as the one shown in Figure 30. Those corners were the ones the package bounced on when dropped.

The stainless steel can (SSC), with fins added to assist in its drop attitude, is pictured in Figure 31. Figure 32 shows the first drop, and Figure 33 shows the effect after the first drop. Damage sustained after both 30-ft drops is illustrated in Figure 34. Both impacts happened between nine and eleven o'clock on the edge of the SSC. Two small dents at the points of impact were the only observable deformations in the SSC.

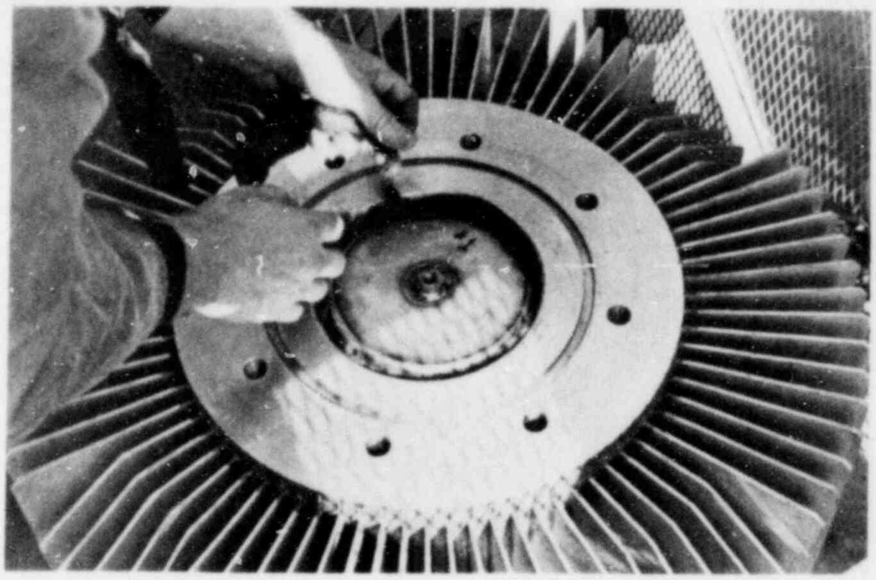

FIGURE 20 - Loading shipping package.

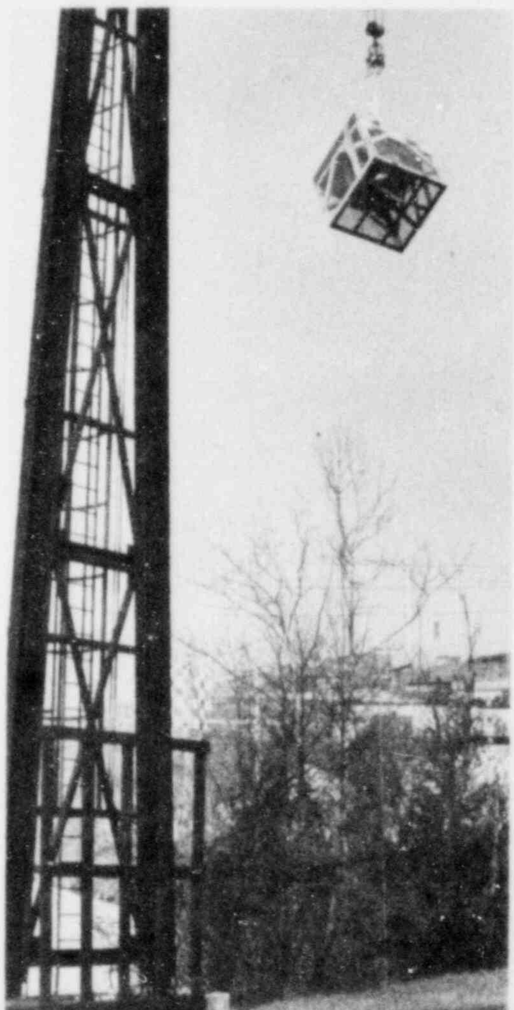

FIGURE 21 - Beginning first 30-ft drop test.

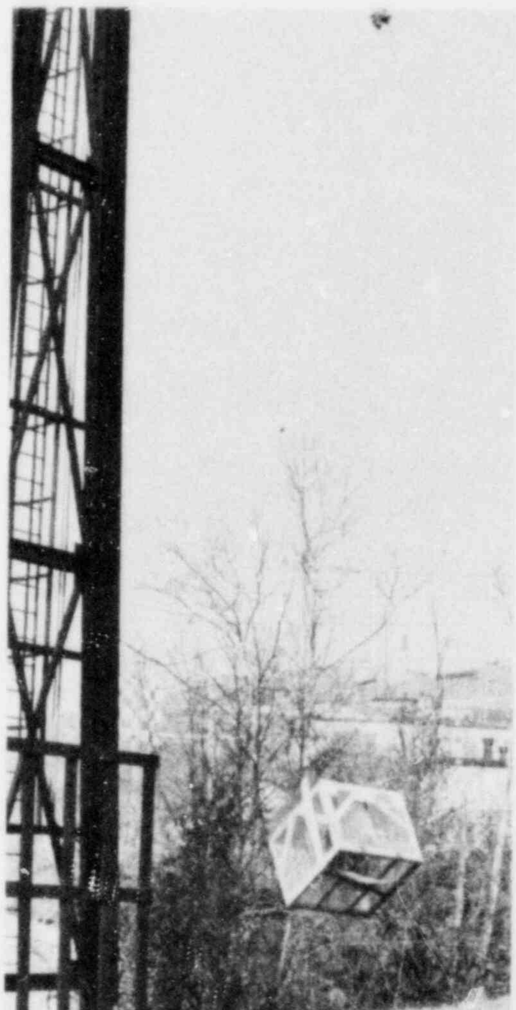

FIGURE 22 - During first 30-ft drop test.

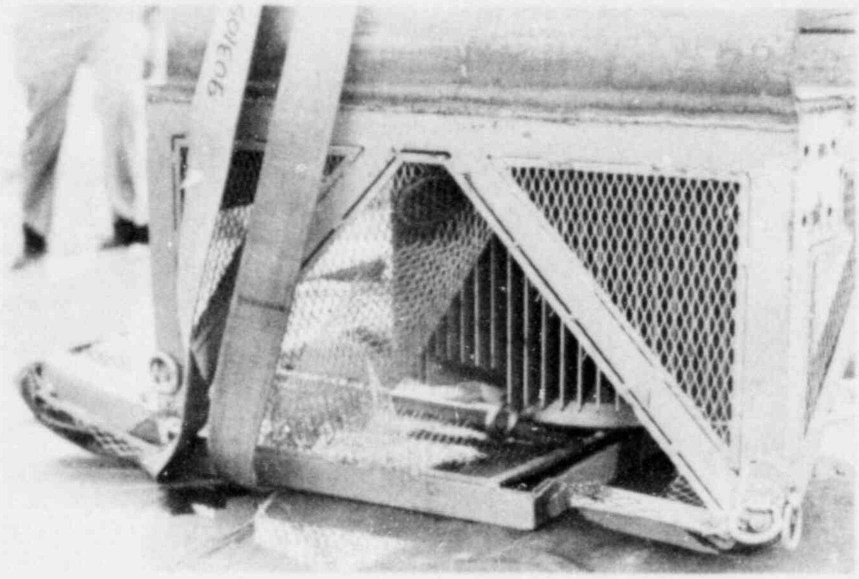

FIGURE 23 - Closeup of damage after first drop.

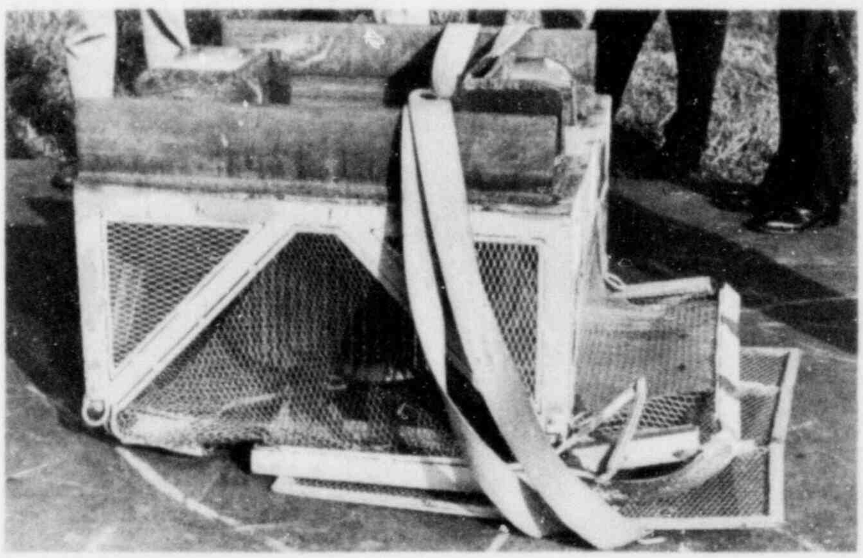

FIGURE 24 - Total damage after first drop.

FIGURE 25 - Beginning second 30-ft drop test.

FIGURE 26 - Landing on left rear corner.

FIGURE 27 - Bounced to right front corner.

FIGURE 28 - Settling on left rear corner.

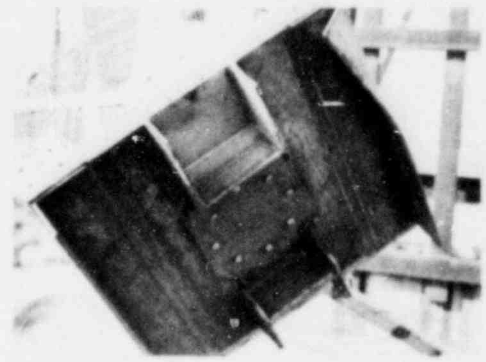

FIGURE 30 - Damage to bottom after drop tests.

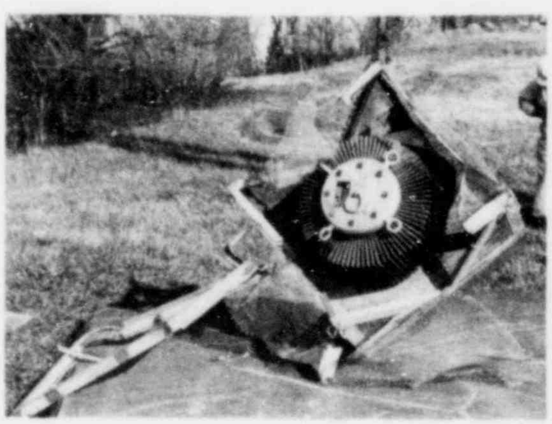

FIGURE 29 - Damage after two drop tests.

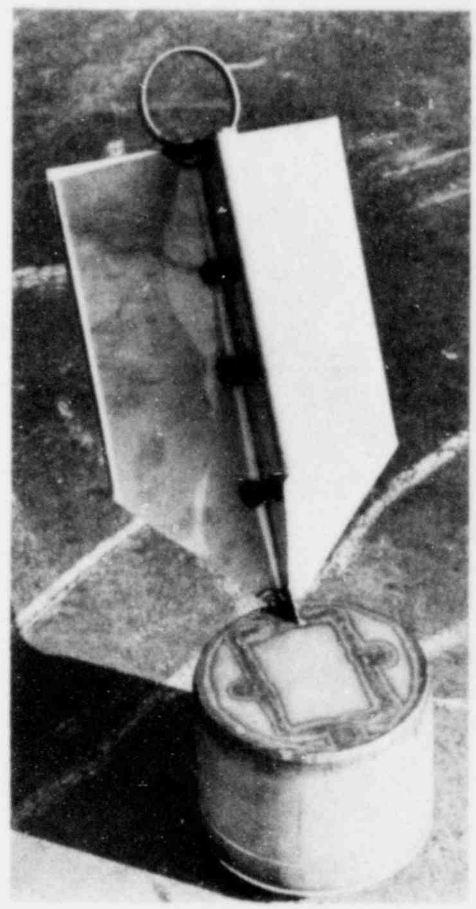

FIGURE 31 - SSC with fins.

FIGURE 32 - First SSC drop test.

FIGURE 34 - Damage after second drop.

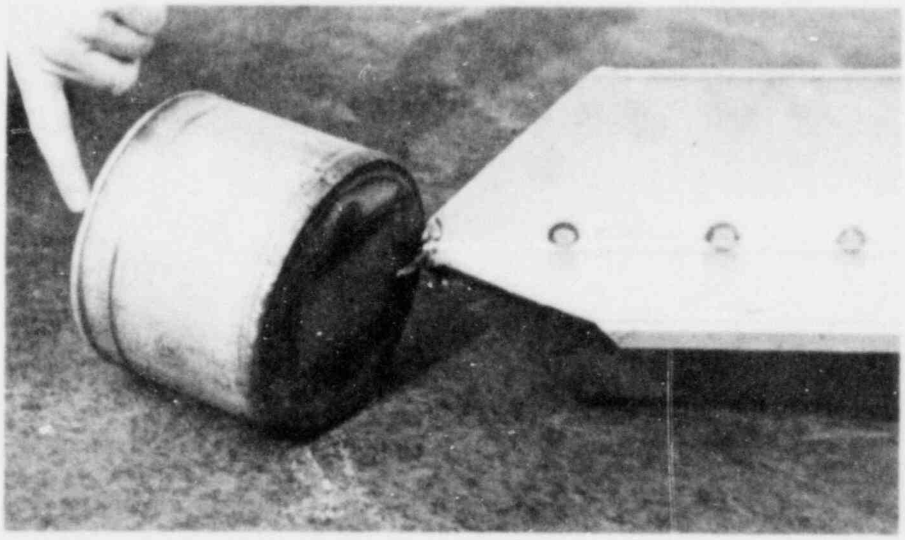

FIGURE 33 - Damage after first drop.

In conclusion, the GPHS module shipping package survived the 30-ft drop test remarkably well. The shipping cage was greatly deformed but still held the finned cask securely. The finned cask was completely undamaged. It was not known what damage the four SSCs inside the finned cask suffered because they were not evaluated at that time. (Refer to "Leak Test and Evaluation").

6.3 Puncture

The puncture test requires a free drop through a distance of 40 in. striking, in a position in which maxium damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar must be 6 in. in diameter and not less than 8 in. long. The long axis of the bar must be perpendicular to the unyielding horizontal surface.

Maximum damage is expected if the GPHS module shipping container were dropped in a flat upside down orientation on the cylinder such that the cylinder could potentially penetrate the finned cask cover. The steel mesh cage will offer no protection after the 30-ft drop. The evaluation, made by comparing the kinetic energy of the GPHS module shipping container on impact with the energy required to shear through the finned cask cover, shows that the finned cask cover would not be penetrated. The kinetic energy is equal to the potential energy of the GPHS module shipping container at a height of 40 in. A weight of 1200 lb was calculated for the entire package, but for the kinetic energy calculation a weight of 1500 lb is used.

The kinetic energy is given by:

$$KE = PE = \frac{40 \text{ in.}}{12 \text{ in./ft}} \; 1500 \text{ lb} = 5000 \text{ ft-lb}$$

The Machinery Handbook gives the equation for calculating the energy required to shear the cask cover as follows:

$$E_p = F_{su} \, (\pi Dt)(t)$$

where

E_p = energy required to shear cask cover,

F_{su} = ultimate shear strength of 304 S.S. at 200°F (60% of tensile), F_{su} = 45,000 psi

D = diameter of potential hole, D = 6 in.

t = cask cover thickness, t = 2 in.

The factor (πDt) is the potential shear area of the hole. Substitution into the above equation yields:

$$E_p = (45{,}000)(\pi \times 6 \times 2)(2) \; \frac{1 \text{ ft}}{12 \text{ in.}}$$

$$E_p = 283{,}000 \text{ ft-lb}$$

The energy required is 56 times the available energy from the drop, and the finned cask cover would, therefore, not be punctured by the cylinder.

A weight of 15 lb was calcuated for the fully loaded stainless steel can, but for the kinetic energy calculation a weight of 20 lb is used. The kinetic energy is given by:

$$KE = PE = \frac{40 \text{ in.}}{12 \text{ in./ft}} \; (20 \text{ lb}) = 67 \text{ ft-lb}$$

The Machinery Handbook gives the equation for calculating the energy required to shear the SSC cover as follows:

$E_p = F_{su}\ (\pi Dt)(t)$

where

E_p = energy required to shear cask cover

F_{su} = ultimate shear strength of 304 S.S. at 200°F (60% of tensile), F_{su} = 45,000 psi

D = diameter of potential hole, D = 0.88 in. (It is more likely that the boss on top of the SSC will be penetrated than the entire SSC cover.)

t = SSC cover thickness, t = 0.125 in.

The factor (πDt) is the potential shear area of the hole. Subsitution into the above equation yields:

$$E_p = (45{,}000)(\pi \times 0.88 \times 0.125)(0.125)\ \frac{1\ \text{ft}}{12\ \text{in.}}$$

$$E_p = 184\ \text{ft-lb}$$

The energy required is more than twice the available energy from the drop. Therefore the SSC cover will not be punctured by the cylinder.

6.4 Fire test

The fire test requires thermal exposure in which the heat input to the package is not less than that which would result from exposure of the whole package to a radiation environment of 1475°F for 30 min.

Figure 35 shows the burn "chamber" before the burn, and Figure 36 portrays the actual burn of the GPHS module shipping container and the SSC.

Six thermocouples were used. Two were placed diagonally from each other on the top outside corners of the shipping cage (left rear edge of cage and right front edge of cage). These two thermocouples were monitored to satisfy the criteria of 1475°F for 30 min. The stainless steel can (module on top of cask) had a separate thermocouple. The remaining three thermocouples were on the finned cask; one on the outside edge of a fin (outside edge of fin), another on the exterior side of the finned cask body (side of finned cask body), and the last inside the finned cask on top of the SSC (inside the finned cask).

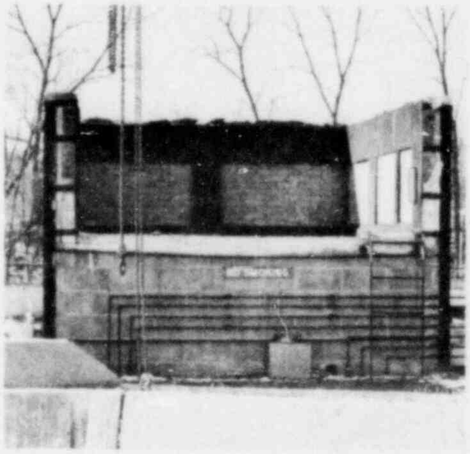

FIGURE 35 - Burn chamber.

FIGURE 36 - Burn of GPHS package.

Figure 37 shows the temperature profile from the six thermocouples during the burn. Note the maximum temperature inside the finned cask reached 510°C (950° F), while the fin edge reached the higher temperature of 655°C (1210°F). The other three thermocouples clearly show that the entire shipping package was subjected to an environment of 1475°F (800°C) for 30 min. These three thermocouples border the shipping package on three sides; left rear, right front, and top. Also take note that one SSC was "burned" separately and reached a maximum temperature of 830°C (1525°F).

Of equal importance is the relative responses of the thermocouples to the input and output (cooling) of heat. The left rear and right front of the cage are close in temperature and have parallel responses. Because the SSC (module on top of cask) is above the front wall of the burn chamber and exposed to cooling air, its temperature

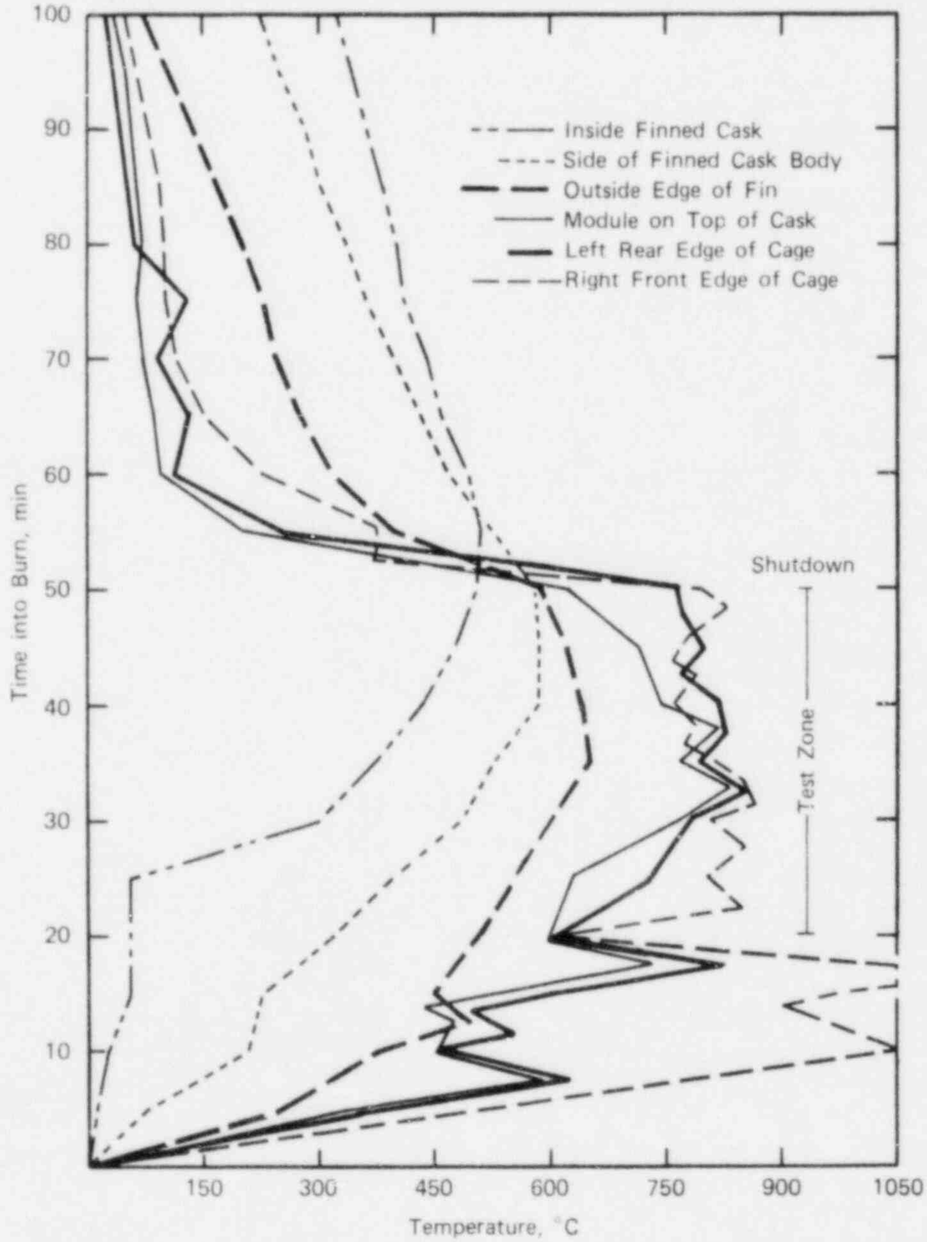

FIGURE 37 - GPHS module shipping container fire test results.

is more erratic than are the left rear and right front. The three thermocouples that are attached to the finned cask rise in parallel, with the fin showing the highest temperatures, followed by the cask body and then the inside cask. The cooling side of the cycle shows just the opposite, as is expected.

When the shipping package was removed from the fire, it was noticed that there was uneven "burning." Figure 38 illustrates the hot side (front of burn chamber). Note that the fins are melted half through and the melted aluminum on the floor of the shipping cage. The "cold" side (back of burn chamber) of the fire is shown in Figure 39 with no aluminum on the floor and the tips of the fins curled a little. Aluminum melts at 1220°F (660°C).

6.5 Water immersion

This test requries that fissile material packages be immersed in water to the extent that all portions of the package to be tested are under water at least 3 ft for a period of not less than 8 hr.

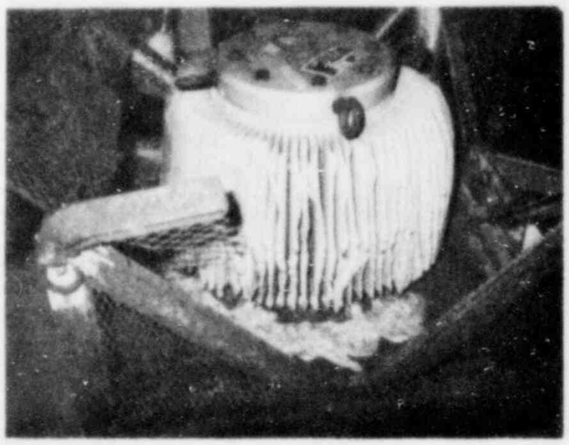

FIGURE 38 - Hot side of package.

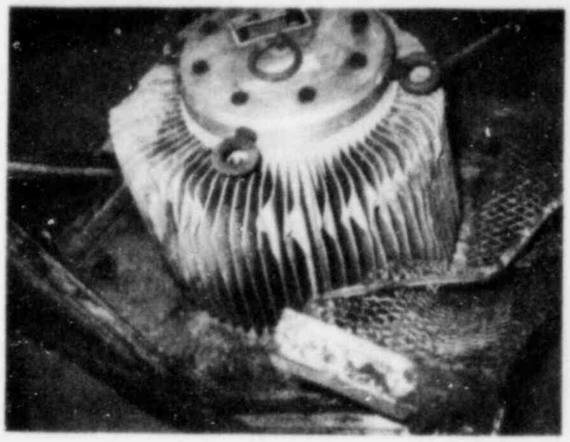

FIGURE 39 - Cold side of package.

Both the GPHS module shipping container and SSC were immersed in at least 3 ft of water for 24 hr. Upon removal of the three SSCs from the finned cask, there was 1-5/8 in. of water in the finned cask. This water was squeezed from the steel wool packing that was around the three SSCs.

6.6 Leak test and evaluation

After the three accident tests (free drop, thermal, and water immersion) had been completed, the four SSCs (three inside the finned cask and the one tested bare) were removed and tested for integrity. Each container was individually placed in a bell jar, which was then evacuated to 0.0 psia and checked for helium. No helium was detected, indicating that any leak in any of the four SSCs was less than 1.0×10^{-8} cm^3/sec. Therefore, the vessels were not leaking.

The containers were then cut open and checked for helium. All four SSCs contained helium. The instrument used in both tests was a Veeco MS-12. These post hypothetical accident tests proved that the exterior integrity of the SSCs were not violated by the hypothetical accidents.

All four SSCs were then opened to inspect their interiors. In all four containers, the graphite rods were cracked and dislodged. Because of this, the hold-down lid for the GPHS module could be easily removed without unscrewing the nuts. Figures 40, 41, and 42 illustrate the interior of the SSCs after the hypothetical accidents. The breaking of the graphite rods is not considered significant. Neither the GPHS module nor the SSC will be damaged by the module not being held securely in the SSC during the accident sequence.

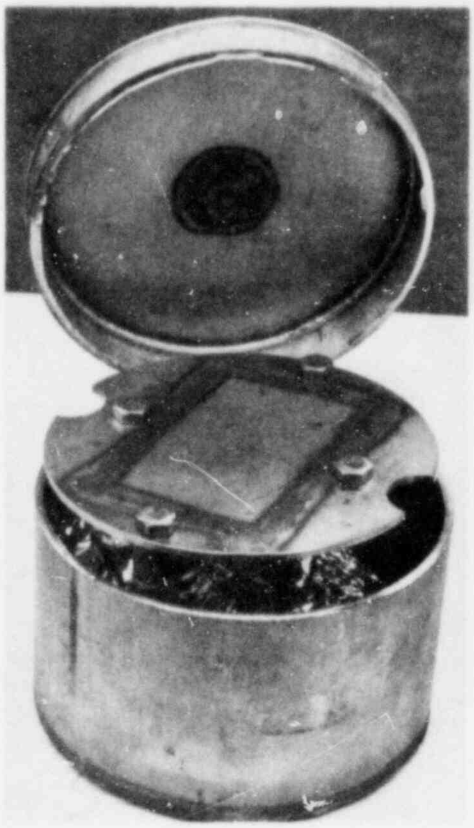

FIGURE 40 - SSC after tests.

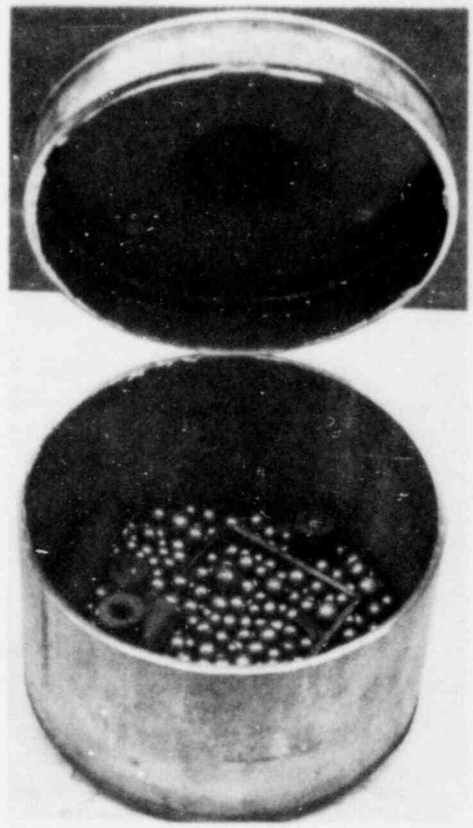

FIGURE 41 - Interior of SSC after tests.

FIGURE 42 - Components of SSC after tests.

7 Criticality analysis

7.1 Introduction

Mound Facility has engineered a package for the shipment of the General Purpose Heat Source (GPHS) components to other DOE contractors. Details of the package are described in Section 2. The package will have a permissable power loading of 750 W(th) or approximately 1363 g of plutonium-238 as the oxide. The outer container is a finned 2R-type cask into which the welded inner containers are placed with some steel wool used as packing. For transport, the cask is bolted to a steel frame and surrounded with a wire cage approximately 3 ft 2 in. on a side. The cage will be moved on the DOE-owned SST vehicles with appropirate tie-downs. It should be noted that this analysis applies solely to the use of this package for transport of plutonium-238. Transport of other fissile materials is not authorized without a separate criticality analysis.

7.2 Assumptions

In the evaluation of the worst case scenario for this package, it is important to note that the isotope plutonium-238 has enhanced neutron multiplication when conditions can provide a fast neutron spectrum, or conversely one can say that a thermalized plutonium-238 system is safe from the aspect of criticality safety. Thus, the most reactive configuration will occur to the damaged 2R containers that have lost the outer wire cage protection and their fins so that they are touching to form an array of cylinders. These 2R-type cylinders are 14-1/2 in. in diameter by 16-3/4 in. high. Any other array of undamaged or damaged containers, moderated or unmoderated would result in a less reactive system. The analysis then is based on a three-dimensional array of cylinders, each containing a maximum of 1500 g of plutonium-238 as the oxide (750 W equivalent + 10%).

7.3 Array limitations

The basis for this analysis is the ANS-8.7 "Guide for Nuclear Criticality Safety in the Storage of Fissile Materials" (ANSI N16.5-1975). The data tabulated in this report are the result of both experimental data and validated calculational techniques such as KENO. The assumption of the analysis is that there are arrays of cubic cells with spherical units of fissile material centered within these cells. This configuration is a conservative approximation of the array of interest. The equivalent cubic cell dimension can be calculated as follows:

Height of cylinder = 16.75 in.
Diameter of cylinder = 14.5 in.
Volume of cylinder = $\pi D^2 H/4$
$= (3.14)(14.5)^2(16.75)/4 = 2764.5 \text{ in.}^3$

The equivalent cubic cell dimension is then

$$A = (2764.5)^{1/3} = 14.03 \text{ in.}$$

With this dimension, the Guide will allow the development of a graph depicting the number of units in a subcritical array for varying amounts of fissile material in each unit. These data are depicted in Figure 43.

7.4 Shipping limitations

The determination of Fissile Class I, Fissile Class II, and Fissile Class III shipping limitations depends on obtaining realistic estimates of the number of shipping containers required to achieve the critical mass of the array.

7.4.1 FISSILE CLASS I SHIPMENTS

Class I shipments may be made only if any number of identical packages would be subcritical. The term "any number" is generally interpreted to be 2500 or more containers. Any package containing an amount equal to or less than the Fissile Class I maximum may be shipped as Fissile Class I. There are no restrictions on the number of packages in Fissile Class I shipments.

7.4.2 FISSILE CLASS II SHIPMENTS

Fissile Class II shipments are based on calculations that demonstrate that at least 25 packages would be required to achieve a critical array. All Fissile Class II shipments must specify a package transport index (T.I.) defined by one of the following relations:

$$\text{T.I.} = \frac{50}{N_u/5} = \frac{250}{N_u}$$

or

$$\text{T.I.} = \frac{50}{N_d/2} = \frac{100}{N_d}$$

whichever is the greater of these two.

In these relations, N_u is the number of undamaged containers required to achieve a critical array, and N_d is the number of damaged containers required to achieve a critical array. The maximum number of packages that can be shipped in a Class II shipment is the number for which the summation of the package transport indices is ≤ 50. This maximum number contains a safety factor of 5; i.e., the maximum permissible number of packages in a shipment is 1/5 the number comprising a critical array. Since 25 undamaged packages are the minimum number comprising the critical array, and greater than 2500 packages is considered an infinite array (Fissile Class I), it can be seen that the transport index will range from 0.1 to 10.0.

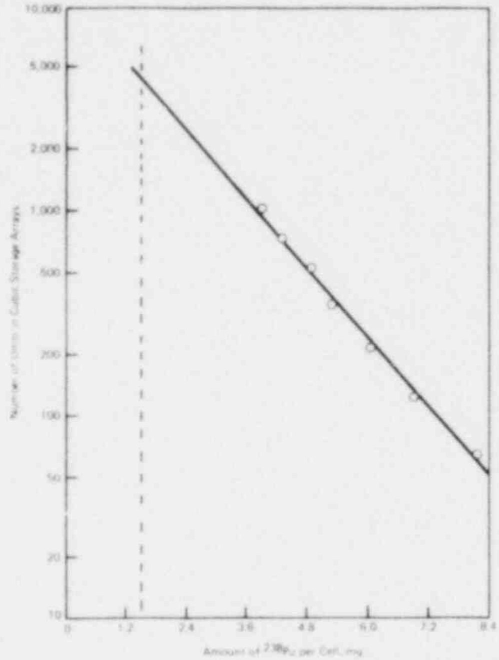

FIGURE 43 · Amount of Pu-238 packaged per container.

7.4.3 FISSILE CLASS III SHIPMENTS

A shipment must be Fissile Class III if the summ. ion of package transport indices exceeds 50 or if the package transport index of any one package exceeds 10. This condition will be met if less than 25 packages will comprise a critical array. The maximum number of packages in a Fissile Class III shipment is 1/3 the number comprising a critical array.

7.5 Results

As can be seen from the plot of the data from Table 4 in Figure 43, the amount of plutonium-238 that can be packaged per container in a 2500-container array is 2.4 kg. For the authorized maximum contents of 1.5 kg, a total of 4400 packages would comprise a subcritical array. Based upon these results, the described package with its authorized contents will be designated as a Fissile Class I package for transport purposes.

Table 4 - AMOUNT OF PLUTONIUM-238 PACKAGED PER CONTAINER

Plutonium-238 Mass Per Package (kg)	Number of Packages Comprising a Subcritical Array
8.1	64
6.9	125
6.0	216
5.3	343
4.8	512
4.3	729
3.9	1000
2.4	2500
1.5	4400

These results are conservative because of the following factors:

a) The maximum credible accident involving loss of both the outer cage barrier and the fins of the 2R inner container is an extremely unlikely occurrence.

b) All values calculated are based on an array with K_{eff} of 0.95 rather than 1.

c) The individual units are assumed to be spherical and totally reflected. Such an optimum configuration will not occur with this container.

As an added check on this unit, another conservative calculational technique can be applied. The Density Analog Method is recognized as a very conservative analytical tool in criticality safety.

The basic equation is as follows:

$$M_c \text{ (reflected)} \leq \frac{M_{so} \text{ (bare)}}{(R)(M_o)} \left(\frac{\bar{\rho}}{\rho_o}\right)^{-S}$$

where

M_c reflected = minimum water reflected critical mass.

M_{so} (bare) = minimum bare critical mass for a particular geometry and atomic ratio.

R = ratio between bare critical mass and water reflected critical mass.

M_o = the contribution from neutron moderation.

$\bar{\rho}$ = density of fissile material per container volume. The reflector savings must be considered whenever significant.

ρ_o = density of the minimum critical mass.

S = depends upon the size of the fissile unit = 2(1-f).

f = ratio of the mass of a single unit to the critical mass of the same fissile material in a similar shape ("fraction critical").

For plutonium-238 oxide the following parameter values are valid.

R = 20, 5 has been used in some previous works although 20 is a better fit to experimental data and adds conservatism.

M_o = 1.0

M_{so} = 25.5 kg

ρ_o = 10.1 g/cm^3

The effective mass of the plutonium-238 per container is the authorized mass of 1.5 kg x reflector savings factor.

M_{eff} = 1.5 kg x 1.728 (Ref. 6)

= 2.592 kg

S = 2(1-f)

f = ratio of the mass (effective) of a single unit to the critical mass of the same fissile material in a similar shape.

= 2.592/25.5

= 0.1016

S = 2(1-0.1016)

= 1.797

Volume of Unit

= $D^2H/4$

= 2765 in.^{3}

= 45310 cm^3

The fuel density $\bar{\rho}$ then becomes

$$\frac{2592\ g}{45310\ cm^3}$$

$$= 0.057\ g/cm^3$$

Then

$$M_c = \frac{25.5(0.057)^{-1.797}}{(20)(1)(10.1)}$$

$$= 13395\ kg$$

$$N = \frac{13395\ kg}{1.5\ kg/container}$$

$$= 8930\ containers$$

This number exceeds by far the criteria for Fissile Class I of 2500 containers remaining subcritical.

8 Radiation shielding evaluation

8.1 General

The neutron and gamma dose rates were measured from two unmodified SNAP-19 shipping containers containing Rite heat sources. Radiation was measured at the points shown in Figure 44.

8.2 Discussion of method and instruments

Two heat sources, Rite I (420 W) and Rite II (820 W) were being stored in separate unmodified SNAP-19 containers. Both Rite

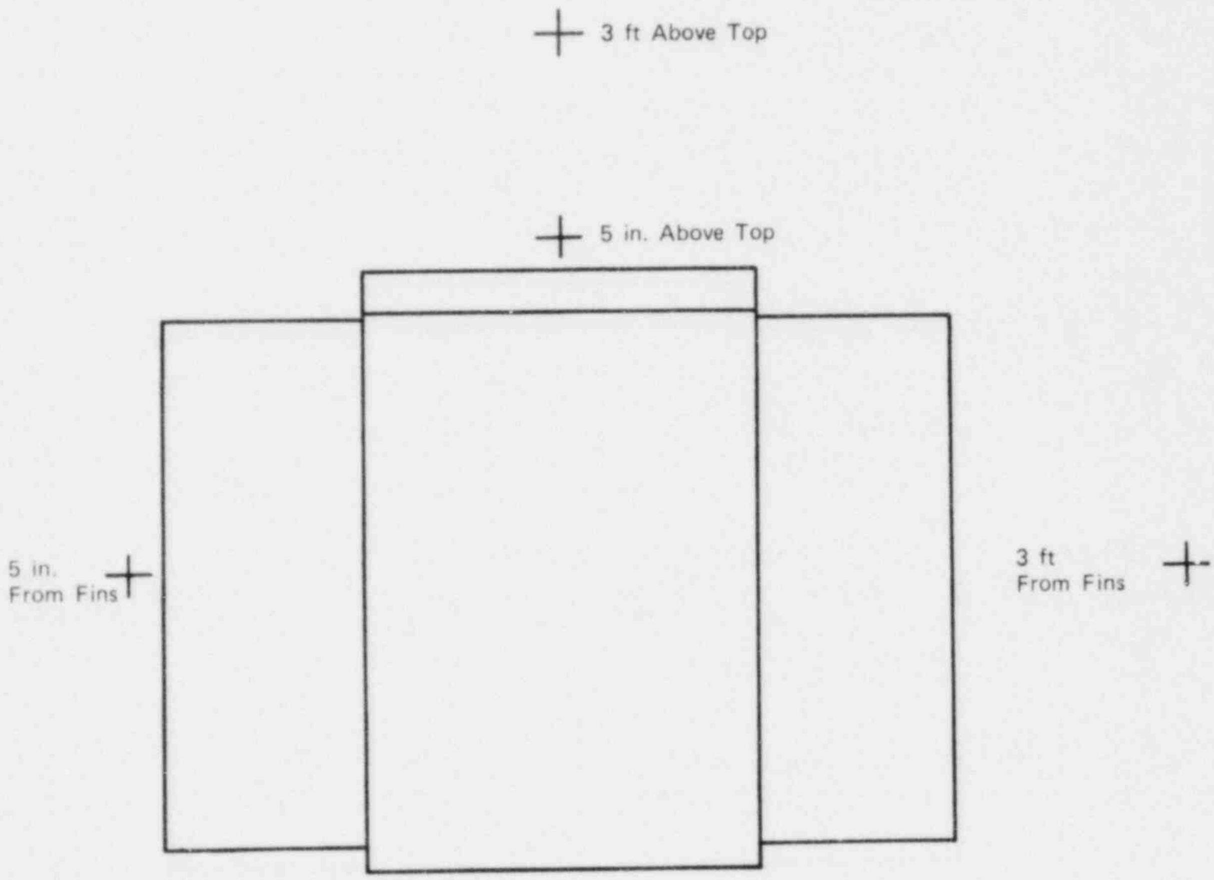

FIGURE 44 - Radiation measurement positions.

heat sources have 80% plutonium-238, whereas the GPHS module has 83.5% plutonium-238. The Rite sources were evenly distributed from top to bottom in the SNAP-19 cavities.

Measurements were taken at 5 in. and 3 ft from the top and at 5 in. and 3 ft from the vertical midpoint of the fins. Each location was counted for 5 min.

The instruments used were a Texas Nuclear neutron "nemo dosimeter" (10-in. Bonner sphere), Model 9140, and a Nuclear Chicago Model 2650 (G.M.) gamma meter. The neutron and gamma instruments were calibrated the day before the actual test. More calibration information is given in Section 8.4.

The containers with sources were removed from the building to reduce the amount of neutron scatter and any background contribution from other sources in the area. Neutron and gamma background levels were established at the sampling site before the sources were removed from the building.

8.3 Results and conclusions

The radiation measurements (Table 5) show that the total dose rate at any accessible point on the surface of the shipping container will be less than 200 mrem/hr. However, the Transport Index, as measured from the side of the shipping container, will exceed 10 mrem/hr, and this will require that such shipments be "sole-use of vehicle."

Radiation measurements were not taken from the bottom of the SNAP-19. It is believed that the forklift would have interfered with the readings; however, the radiation from the bottom is not more than the radiation from the top. That assumption is based on two parameters: 1) the source is uniformly distributed within the SNAP-19 cavity; and 2) the top cover is 2 in. thick and, although the bottom is 1.5 in., the bottom of the shipping cage will add another 0.75 in. of steel. Thus, the total shielding on the bottom is 2.25 in. versus 2.00 in. on the top.

Table 5 - RADIATION MEASUREMENTS OF FINNED CASK WITH RITE-I AND RITE-II HEAT SOURCES STORED INSIDE

	Rite-I 420 W				Rite-II 820 W			
	Total Count	mrem/hr			Total Count	mrem/hr		
		n	γ	Total		n	γ	Total
3 ft from top	3,600	2.7	0.6	3.3	20,540	15.2	.8	16.0
5 in. from top	31,340	23.2	3.8	27.0	179,140	132.6	5.5	138.1
3 ft from fin	3,050	2.3	0.5	2.8	20,770	15.4	1.00	16.4
5 in. from fin	20,430	15.1	4.2	19.3	130,100	96.3	7.3	103.6

Note that the radiation measurements were made without the shipping cage. Three feet from the SNAP-19 finned cask is equivalent to 2 ft from the shipping cage.

Table 5 shows the GPHS 750-W shipping container will yield 12.0 mrem/hr 3 ft from the fins or top, 74.0 mrem/hr 5 in. from the fins, and 104 mrem/hr 5 in. from the top.

If it is assumed that the cage is removed from the finned cask, and the fins are melted from the cask, the maximum radiation 3 ft from the package surface will be less than 75 mrem/hr. Five inches from the fins (11 in. from the cylinder wall) the radiation is 74 mrem/hr. Moving another 2 ft from that point and removing the fins will produce a dose rate of less than 74 mrem/hr. Three feet from the top (2 in. of shielding) the dose is 16 mrem/hr. Three feet from the bottom (1.5 in. of shielding) the dose will be higher than 16 mrem/hr but significantly less than 75 mrem/hr. These dose rates meet the criteria specified in DOE Chapter 0529, which requires that the radiation dose rate remain under 1000 mrem/hr at 3 ft from the surface in hypothetical accident conditions.

8.4 Calibration information and quality assurance documents

MONSANTO RESEARCH CORPORATION — *Inter-Office Correspondence*

From LOCATION : Health Physics, SM-PP-WD

cc: R.T. BRASHEAR
FILE

DATE : September 25, 1979

SUBJECT : INSTRUMENT CALIBRATION AND SENSITIVITY

REFERENCE : DOSE RATES OF SNAP SOURCES

TO : Michael A. Whitney

On Tuesday, August 21, 1979 at 9:30 a.m., a series of neutron and gamma readings were taken on two SNAP (19?) sources located in Bldg. 50, Cell 111. The sources were removed from the building to reduce the amount of neutron scatter and any background contribution from other sources in the area. Neutron and gamma background levels were established at the dose rate site before the sources were removed from Bldg. 50. Dose rates were taken on each source separately (one source always remained inside the building).

The instruments used for this purpose were a Texas Nuclear neutron "nemo dosimeter" (10" Bonner sphere), Model 9140 and a Nuclear Chicago Model 2650 (G.M.) gamma meter. The neutron instrument was checked for calibration on Monday, 8/20/79 using a Pu Be neutron source ($Q=8.6 \times 10^5$ N/Sec). The 10" Bonner sphere (detector) was exposed to a 22 mrem/hr. neutron field at a distance of 20 cm. ($Q \cdot E/4\pi r^2$ der) this yielded 266C.P.M. per millirem. Additionally, the instrument was checked for gamma sensitivity by placing the sphere in a 50 mrem/hr. gamma field at a distance of 20 cm. using a 1.54 milli Ci Cobolt 60 source. This yielded 0.8C.P.M. per mrem, or a neutron to gamma ratio of 0.8/266 = <u>1:0.003</u>.

Hence: in a uniform field (1.0 mrem/hr. neutron and 1.0 mrem/hr. gamma) the amount of error introduced into the neutron dose rate due to gamma radiation would be ~ 0.3%. As the actual neutron to gamma ratio was much higher than this, the percent of error due to gamma radiation was proportionately lower (i.e., probably < <u>0.03%</u>). The Model 2650 gamma instrument was also checked for calibration using the 1.54 milli curie Cobolt 60 source referenced above. It was not necessary to do reciprocal sensitivity testing on the Model 2650 Geiger-Mueller gamma meter as this instrument readily discriminates neutron radiation.

<u>Note</u>: Both the Cobolt 60 gamma source and the Pu Be neutron source are traceable to N.B.S.

W. K. Wallace
W. K. Wallace

WKW:rc

Calibration of Thermocouples for Temperature
Measurement on Finned Cask and SSC

Thermocouples for measuring temperature were calibrated as follows:

1. The thermocouples and a liquid glass thermometer were placed inside a furnace where the temperature reached 200°F. The accuracy of this calibration is ±2°F.

2. The thermocouples were placed in an ice bath where the temperature is constant 32°F. The accuracy of this calibration is ±0.2°F.

The overall accuracy of the thermocouples used to measure the temperatures of the shipping container is ±2°F.

Rick A. Hecathorn
Rick A. Hecathorn

Poco Graphite.

A Union Oil Company of California subsidiary
1601 South State Street, Decatur, Texas 76234
Telephone (817) 627-2121 • TWX 910-890-5724

union 76 POCO

Monsanto Research
Mound Facility
Miamisburg, OH 45342

November 1, 1979

CERTIFICATE OF COMPLIANCE

This is to certify that the material shipped on your purchase order 37843-25, our sales order number 12104, meets or exceeds our currently published specifications for grade AXF.

Signed [signature]

Title Quality Control, Supervisor

18 pcs. 5/8 Ø x 12

Material shipped on this purchase order is certified to have been manufactured under an established and approved proprietary process and that the process was inspected, monitored and tested for compliance with published quality and physical properties for the grade of material stated above. Recorded results of our quality and monitoring inspections and evaluations are on file at Poco Graphite and in compliance with our STANDARD PROCEDURES Section IV, Items 9 and 13 (proprietary).

This part was manufactured from billet FH324 in accordance with Specification ACO-780479M2-C.

Customer Services

Poco Graphite, Inc.
A Union Oil Company of California subsidiary
1601 South State Street, Decatur, Texas 76234
Telephone (817) 627-2121 • TWX 910-890-5724

union 76 POCO

Monsanto Research Corp. April 15, 1980

CERTIFICATE OF COMPLIANCE

This is to certify that the material shipped on the following purchase order(s) was manufactured by Poco Graphite, Inc. in accordance with established proprietary procedures. The properties of such material is judged to fall within the range of those physical and chemical properties appearing in our sales literature, which is based on certain key test information obtained on the material specifically sold to the customer and on other additional key test data obtained on random samples taken on a routine, periodic basis.

Your Purchase Order No. 43C95-25

POCO Sales Order No. 13383

Material Grade AXF

Special Processes N/A

Size and Quantity 4 pcs. 5/8 Ø x 12

Serial Numbers (as required) N/A

Remarks N/A

Quality Control Manager

CRUCIBLE INC-TRENT TUBE DIVISION

EAST TROY, WISCONSIN 53120

Stainless Steel Tubing

RECEIVED 17-APR-79 Change Order

CUSTOMER ORDER NO.	CPO. DATE	RATING	ENTRY DATE	SHIP	MARKS	MILL ORDER NO.
CHIP 10725 1	03/30		04/02/79	P	SPT FLOW	7C5-4[illegible]-9-

TUBCARR I 25234 21 TUBCARR 25234

TR

SOLD TO: TUBESALES
235 TUBEWAY
CAROL STREAM, ILL 60187

SHIP TO: TUBESALES
235 TUBEWAY
CAROL STREAM, ILL 60187

SPECIAL INSTRUCTIONS

F.O.B. TERM

6000 120 A0017240001 220 | 7.606 LB/FT | SOURCE

3.000 X .120 17 - 24 FT RML
FULL FINISHED ANNEALED & PICKLED

ASTM A269 A249 AV
TYPE 304

600 FT
4564 LBS
PCS
05/14/79 WAI
05/21/79 PRC

SHIPPING NOTICE

M. O. NUMBER 7C5-45279-9

FT. 589.915
NET 4530
PCS. 28
GROSS 5140
6 Boxes - Comp
DATE 5/30/79
B.L. NO. C-019670
Spector Frt - PPD
HEATS 825078

REPORT OF TESTS

SHIPPED	HEAT NUMBER	FEET	PCS.
HEAT A	825078	589.915	28
HEAT B			
HEAT C			

SHIPPED FROM Carrollton 7C5-45279-9

NON-DESTRUCTIVE TESTING
EDDY CURRENT ☐ OTHER
PRESSURE: AIR ☐ HYDRO ☒ 600 PSI
CORROSION RESISTANCE
ASTM-A-262 PRACTICE

CHEMICALS	C	MN	P	S	SI	NI	CR	MO	TI	CU	CO	
HEAT A	.06	1.67	.020	.024	.62	8.61	18.25	.09		.05	.04	Type 304 ASTM A-269 ASTM A-249 AVE
HEAT B												
HEAT C												

MECHANICALS	TENSILE PSI	YEILD PSI	ELONG.%	HARDNESS	FLANGE	FLAT	FLARE	REV. FLAT	REV. BEND	GRAIN SIZE
HEAT A	83,800	45,200	61%	B-79	OK	OK	OK	OK	OK	
HEAT B										
HEAT C										

REMARKS

WE HEREBY CERTIFY THIS REPORT TO BE TRUE AND CORRECT ACCORDING TO RECORDS IN POSSESSION OF THIS CORPORATION.
TRENT TUBE DIVISION — CRUCIBLE INC

SIGNED N. Ralston

SWORN TO AND SUBSCRIBED BEFORE ME

THIS ______ DAY OF ______ 19 ______

MY COMMISSION EXPIRES ______ NOTARY

INSPECTION REPORT

NONDESTRUCTIVE EVALUATION

Program:	
Subject:	WELD TUBES
Technique:	FLUORESCENT DYE PENETRANT INSPECTION
Examined by:	O°W°DODDS
Date:	11-1-79
Part:	(9) tubes welded.
Serial No.:	NA. = (no serial No.)
Decision:	Eight tubes are acceptable on fluorescent dye penetrant inspection.
Comments:	One tube weld has two large pores or dross like indications on inside weld, Part is marked to locate dye indications.

MHC-ML-3128

Approved by: [signature]

Date 3-5-80

Distribution:
M. Whitney
File:

FLUORESCENT DYE PENETRANT REPORT

Item: TUBE WELD (g.p.h.s.)

A fluorescent dye penetrant inspection was made on outer weld surface, and inner weld surface.

RESULTS: No apparent dye penetrant indications to indicate weld defects.

Acceptable on dye penetrant inspection.

Inspected in accordance with ASTME-165
Procedure A-2

Inspected by [signature]

Date 4-17-80

M. Whitney
File:

FLUORESCENT DYE PENETRANT REPORT

Item: TUBE (6". Diam.) GPHS

The 6" Diam tube was given a dye penetrant inspection on all welds .

Two locations on one weld had dye penetrant defects and was ground out and inspected again (then accepted on dye penetrant.).

The areas ground on the one weld is not two thin so Re-welding is not needed.

Inspected by Orein Dolds

References

1. "Safety Standards for the Packaging of Radioactive and Fissile Material," DOE Manual, Chapter 0529, U. S. Department of Energy, Washington, D.C., pp. 1-21.

2. J. M. Guy, et al., ASME Boiler and Pressure Vessel Code, Section VIII, Rules for Construction of Pressure Vessels, Division I, The American Society of Mechanical Engineers, New York, NY (1980).

3. "Tiedown for Transport of Fissile and Radioactive Material Containers Greater than One Ton," (Tentative RDT Standard) Division of Reactor Development and Technology, USAEC (June 1973).

4. L. B. Shappert, Cask Designers Guide: A Guide for the Design, Fabrication, and Operation of Shipping Casks for Nuclear Operations, ORNL-NSIC-68, Oak Ridge, TN (February 1970) 238 pp.

5. E. Oberg and F. D. Jones, Machinery Handbook, 19th ed., Industrial Press, Inc., New York, NY (1971), 2420 pp.

6. D. R. Smith, "Criticality Safety Evaluation of Packages for the Transportation of Fissile Material," Proceedings of the International Symposium for Packaging and Transportation of Radioactive Materials, held at Albuquerque, New Mexico, January 12-15, 1965, SC-RR-65-98, Sandia Corporation, Albuquerque, NM (June 1965), pp. 675-690.

DOE Form EV418
(11-77)
10 CFR 71

U.S. DEPARTMENT OF ENERGY
CERTIFICATE OF COMPLIANCE
For Radioactive Materials Packages

1a. Certificate Number	1b. Revision No.	1c. Package Identification No.	1d. Page No.	1e. Total No. Pages.
9510	0	USA/9510/BLF(DOE/AL)	1	2

2. PREAMBLE

2a. This certificate is issued to satisfy Sections 173.393a, 173.394, 173.395, and 173.396 of the Department of Transportation Hazardous Materials Regulations (49 CFR 170-189).

2b. The packaging and contents described in item 5 below, meets the safety standards set forth in Subpart C of Title 10, Code of Federal Regulations, Part 71, "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions."

2c. This certificate does not relieve the consignor from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or into which the package will be transported.

3. This certificate is issued on the basis of a safety analysis report of the package design or application—

(1) Prepared by *(Name and address)*:	(2) Title and identification of report or application:	(3) Date:
Monsanto Research Corp. Mound Facility Miamisburg, Ohio 45342	MLM-2857 Safety Analysis Report for Packaging General Purpose Heat Source Module 750 Watt Shipping Container	October 1981

4. CONDITIONS

This certificate is conditional upon the fulfilling of the requirements of Subpart D of 10 CFR 71, as applicable, and the conditions specified in item 5 below.

5. Description of Packaging and Authorized Contents, Model Number, Fissile Class, Other Conditions, and References:

A. DESCRIPTION OF PACKAGING

The General Purpose Heat Source Shipping Container (GPHS) consists of several parts which include:

1. A cage type "carrier" which is fabricated of steel. The base of the carrier serves as a pallet and provides a means to secure the shipping container in the transport vehicle. The carrier is of welded construction weighing approximately 300 lbs. with dimensions of 38 in. cube.

2. A finned cask is made of stainless steel with 80 aluminum fins which are designed to dissipate 750 watts of heat. The overall height is slightly less that 19 inches, and the overall diameter from fin tip to fin tip is 25½ inches. The weight is approximately 800 lbs.

3. Three inner containers called the Stainless Steel Cans (S.S.C.) are stacked on top of each other inside the finned cask. The S.S.C.'s hold the General Purpose Heat Source (GPHS) inside. Each S.S.C. is a completely welded 304 SS cylinder made of a 6 inch diameter X .120 wall X 4½ inch height tubing with a base plate of 6 inch diameter X .125 in. thick and a cover plate 5 7/8 in. diameter X .125 in. thick.

B. AUTHORIZED CONTENTS

The contents of the shipping container consists of three GPHS - Modules producing a total of 750 Watts of heat from 1360 gram ^{238}Pu solid oxide. The overall dimensions of a module are 2.14 in. X 3.71 in. X 3.81 in. Each fuel pellet is contained in a vented iridium capsule, and two of the iridium capsules are enclosed in a single impact shell, which is enclosed in two layers of pyrolytic graphite. Two of these pyrolytic graphite-enclosed impact assemblies are held in a re-entry member.

C. Fissile Class I

6a. Date of issuance October 5, 1981	6b. Expiration Date N/A

FOR THE U.S. DEPARTMENT OF ENERGY

7a. Address *(of DOE Issuing Office)*	7b. Signature, Name, and Title *(of DOE Approving Official)*
Albuquerque Operations Office P. O. Box 5400 Albuquerque, NM 87115	Jack R. Roeder Jack R. Roeder, Director, Operational Safety Division

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